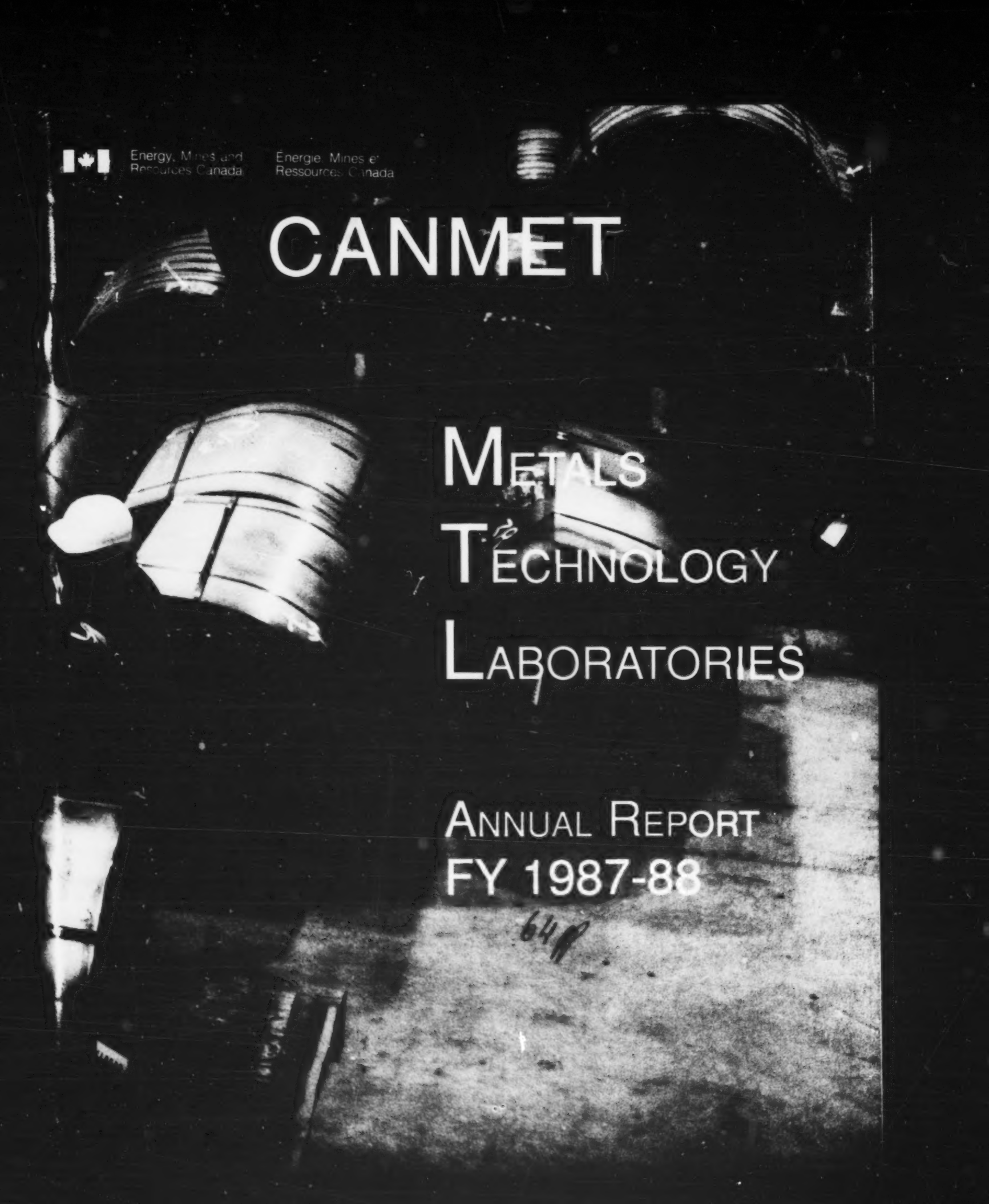

Energy, Mines and Resources Canada

Énergie, Mines et Ressources Canada

CANMET

METALS TECHNOLOGY LABORATORIES

ANNUAL REPORT FY 1987-88

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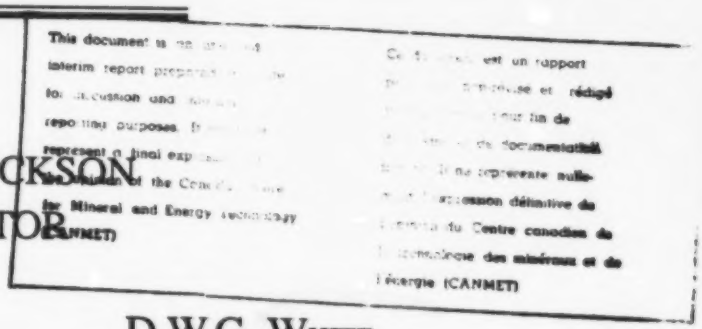
CANMET

METALS TECHNOLOGY LABORATORIES

ANNUAL REPORT FY 1987-88



W.H. ERICKSON
DIRECTOR

R. THOMSON
MANAGER
METALS PROCESSING
LABORATORY

D.W.G. WHITE
MANAGER
METALS DEVELOPMENT
LABORATORY

MTL 88-31 (TR)

MICROMEDIA

PATENTS AND SPECIAL HONOURS

A.F. Crawley, C. Galvani and E. Cousineau received the Mechanical Working and Steel Processing Conference **Meritorious Award** from the Iron and Steel Society U.S.A. for "Precipitation and textural effects on rapid annealing of cold rolled aluminum killed steel".

Mahi Sahoo and Lawrence Whiting, Foundry Section, were awarded a **patent** "Zinc-aluminum alloy sand castings"; Canadian Patent No. 1 230 993; filed Nov. 2, 1984.

Mahi Sahoo and J.O. Edwards received the **Best Paper** award from the Brass and Bronze Division of the American Foundrymen's Society for "Pouring rate versus velocity - A study of gating system for copper-base alloys".

Mahi Sahoo, Don Brown, Bob Buhr, Earl Darke, Keith Davis, J.L. Dion, Henri-Paul Guindon, Richard Lacroix, Jean-Guy Magny, Rejean Matte, Mahi Sahoo, Dick Warda and Lawrence Whiting, Foundry Section, received the Government of Canada **Award of Excellence** for their contribution to the Mobile Foundry Laboratory Project.

FOREWORD

Preparing introductory comments for our Annual Report always provides the welcome opportunity to highlight the recent achievements of these laboratories. I am particularly enthusiastic about writing a Foreword at this time because we are moving forward rapidly and with a sense of purpose. Following a period of public debate and self assessment on the role and operation of government research organizations, positive action has been taken in the past year to sharply focus on CANMET's mission and to fulfill that mission.

As a Federal Government Technology Centre, CANMET is mandated to carry out research and development (i) to enhance the competitiveness of the Canadian mineral, metal and energy industries, (ii) to improve health, safety and environmental control in the client industries, and (iii) to support government policy initiatives pertaining to the client industries.

To more accurately reflect our activities as one of the five CANMET research divisions, the name METALS TECHNOLOGY LABORATORIES (MTL) has replaced the former Physical Metallurgy Research Laboratories (PMRL). More important, we have re-structured all of our research activities into four major programs to clearly show the relationship between MTL projects and the client industries. The four programs are: (i) Steel Technology (ii) Foundry Technology (iii) Non-Ferrous Advanced Materials (iv) Materials for Resource Industries

Although this re-structured organization has only existed for several months, it is already evident that each of the four programs can be managed essentially independently, but at the same time they promote interdisciplinary activity throughout MTL. It is also anticipated that it will be easier for our client industries to identify with particular research groups in MTL and easier for us to work consistently with industry to market our capabilities, and develop joint, and to the extent possible, cost-shared projects. To provide further guidance for project development, Technical Advisory Groups (TAG's) have been established for each of the four programs. The TAG's are composed of technical experts from industry and universities.

MTL's activities for 1987-88 are summarized in the following pages in the format of the new program structure. MTL continues to produce research of high quality and in quantity, which is relevant to the needs of the Canadian metals industry. The individual project descriptions in this Annual Report are necessarily brief, but I encourage you to contact MTL staff for additional information on any project. Particularly noteworthy are the new research activities which were established during the past year: the secondary ion mass spectrometer (SIMS), the facility for direct casting of steel strip, and the research group for metal matrix composites. MTL staff continues to make a substantial contribution to national and international technical activities by serving on committees, organizing symposia, writing standards, and editing publications. I wish to particularly congratulate those people who have been recognized by their peers with awards and other distinctions.

W.H. Erickson
Director
(613) 995-8248

AVANT-PROPOS

La rédaction de commentaires préliminaires pour notre Rapport Annuel est toujours une occasion propice de mettre en évidence les réalisations récentes de nos laboratoires. A la suite d'une période de remise en question du rôle et du mode de fonctionnement des organisations gouvernementales de recherche, je suis heureux de constater qu'une action positive a été entreprise au cours de l'année qui vient de s'écouler afin de définir clairement le mandat de CANMET et les moyens à prendre pour remplir ce mandat.

En tant que Centre de Technologie du Gouvernement Fédéral, le mandat de CANMET est d'effectuer des activités de recherche et de développement dans le but (1) d'améliorer la compétitivité des industries minérales, métallurgiques et énergétiques canadiennes, (2) d'améliorer la santé, la sécurité et le contrôle de l'environnement dans ces industries, et (3) de soutenir les politiques gouvernementales se rapportant à ces industries.

Afin de réfléter plus fidèlement nos activités au sein des cinq divisions de recherche de CANMET, le nom de Laboratoires de la Technologie des Métaux (LTM) a été choisi pour remplacer l'appellation précédente Laboratoires de Recherche en Métallurgie Physique (LRMP). De plus, toutes nos activités de recherche ont été restructurées en quatre programmes principaux qui établissent clairement les relations entre les projets de recherche à LTM et les industries concernées. Ces quatres programmes sont: (i) Technologie des Aciers, (ii), Technologie de Fonderie, (iii) Matériaux Non-ferreux de Pointe, (iv) Matériaux pour les Industries de Ressources

En dépit du fait que cette nouvelle structure n'existe que depuis quelques mois, il est déjà évident que chacun des quatre programmes peut être administré de façon indépendante tout en permettant une activité interdisciplinaire intense. Nous anticipons également qu'il sera plus facile à notre clientèle industrielle de s'identifier à des groupes de recherche particuliers au sein des LTM. En retour, il nous sera plus aisé de promouvoir nos compétences, de travailler de concert avec les industries, de développer des projets conjoints et, dans la mesure du possible, d'en partager les coûts.

Des Groupes de Conseillers Techniques (GCT) ont été formés pour chacun des quatre programmes. Ces GCT sont composés d'experts techniques provenant des milieux universitaires et industriels et ils ont pour mandat d'orienter le développement de nouveaux projets dans chaque programme.

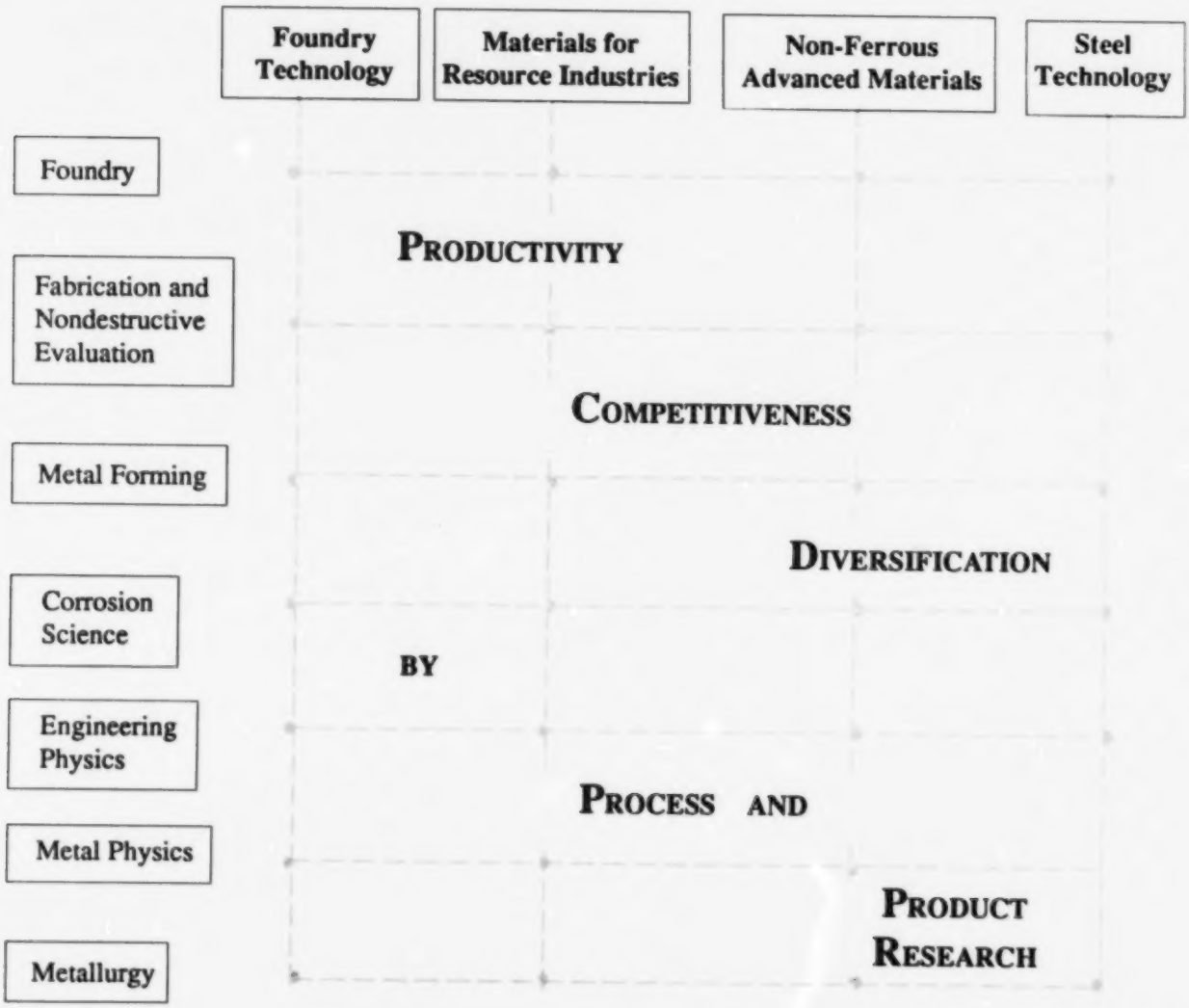
Les activités des LTM au cours de l'année 1987-88 sont résumées dans les pages qui suivent en se basant sur la nouvelle organisation des programmes de recherche. Les LTM continuent de produire une recherche abondante et de haute qualité, qui est pertinente aux besoins de l'industrie canadienne des métaux. Les projets individuels sont décrits brièvement dans ce Rapport Annuel, mais le personnel des LTM sera heureux de fournir tous les renseignements additionnels désirés. Des activités de recherche nouvelles ont été entreprises durant l'année venant de s'écouler: spectromètre de masse à ions secondaires (SIMS), installations permettant la coulée directe de feuillards d'acier, groupe de recherche en matériaux composites à matrice métallique. Le personnel des LTM continue de contribuer de façon significative aux activités techniques nationales et internationales en s'impliquant dans des comités, par l'organisation de colloques, en rédigeant des normes et en éditant des publications. Je désire féliciter plus particulièrement les employés des LTM dont les aptitudes ont été reconnues par leurs pairs par le biais de prix et autres distinctions.

W.H. Erickson
Directeur
(613) 995-8248

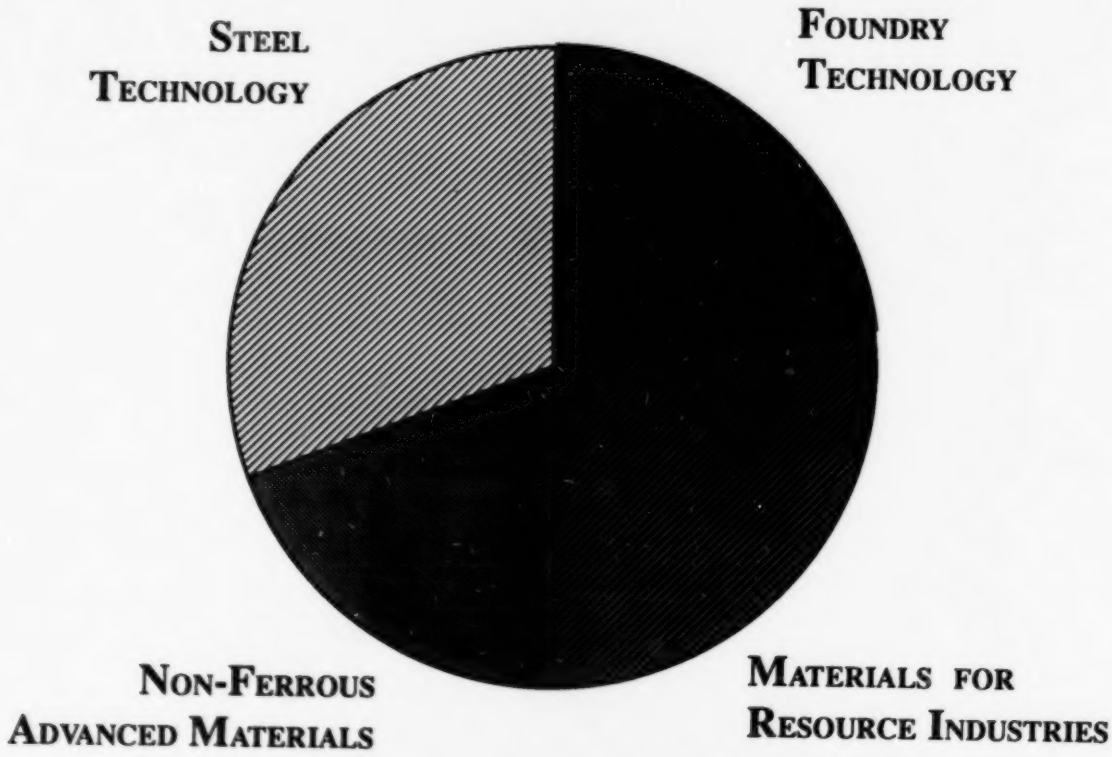
Organization of the Metals Technology Laboratories

The Metals Technology Laboratories (MTL) perfom research in four program areas : Foundry Technology, Steel Technology, Advanced Materials and Materials for Resource Industries. To support these four programs these Laboratories are organized into seven sections providing seven areas of generic expertise. The objective of MTL's research and technology programs is to provide technical support for the Canadian Minerals and Energy Industry and to promote productivity, competitiveness and diversification.

MTL has a staff of about 130. Of these about 55 are scientists or engineers and 50 are technologists or technical support staff. In addition throughout the year MTL has some 25 visiting staff composed of students, postdoctoral fellows and workers from industry.



Allocation of MTL Person Year (PY) Resources by Research Program Area



The Number of MTL Staff Directly Involved In Research and Development is 113.

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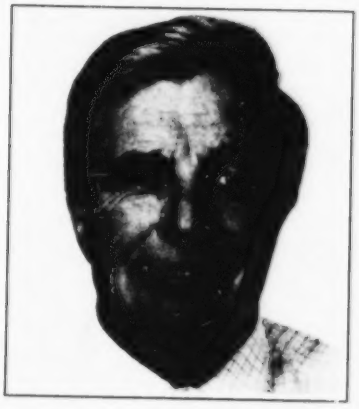
Dr. D.W.G. White

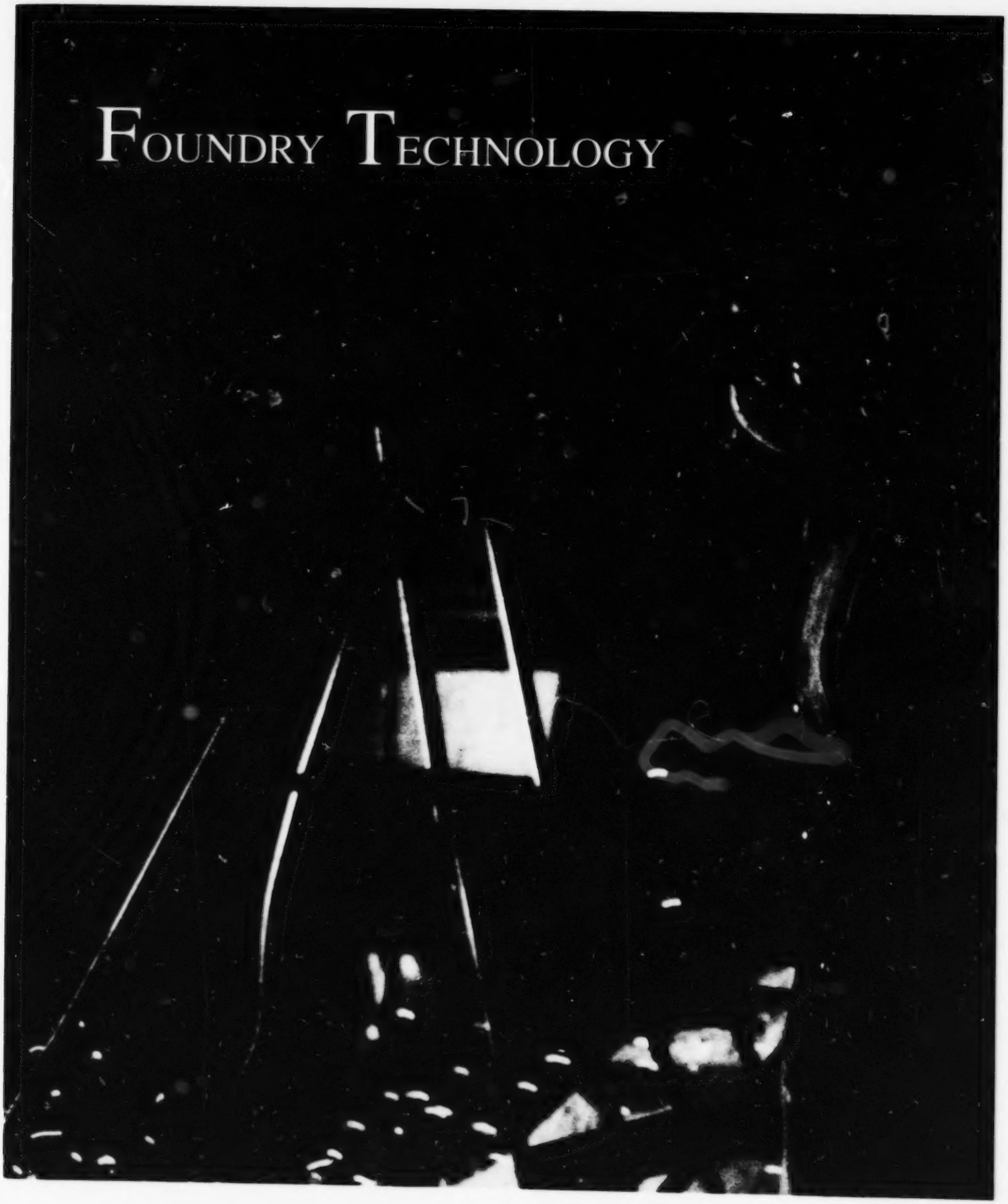
Manager
Metals Development Laboratory
995-2828

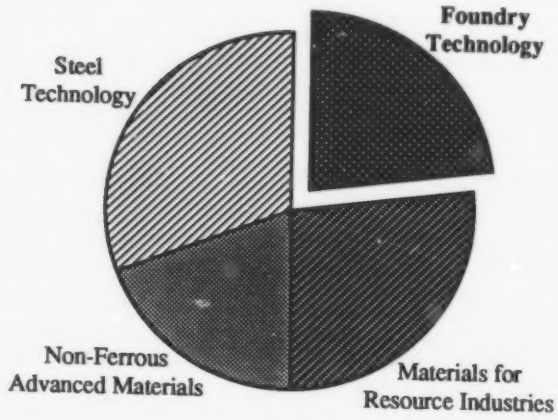
Dr. R. Thomson

Manager
Metals Processing Laboratory
995-9541

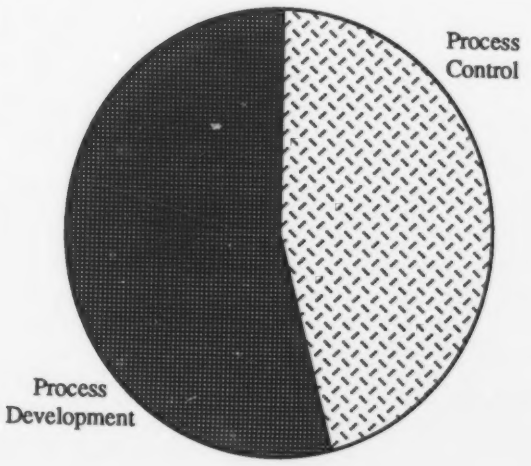


Foundry Technology





FOUNDRY TECHNOLOGY PERSON YEAR ALLOCATION BY PROJECT AREA



PROCESS CONTROL

* Automated Casting Process
* Electric Furnace Cost Analysis
* Real Time Process Control
* Green Sand Evaluation Studies

PROCESS DEVELOPMENT

* Gravity Permanent Mould Casting
* Austempered Ductile Iron
* Zinc-Aluminum Alloys
* Antimony in High-Leaded Tin Bronzes

BOB BUHR (LEFT)
992-5095

DICK WARDA (RIGHT)
992-0949

MANAGERS OF THE FOUNDRY TECHNOLOGY PROGRAM

FOUNDRY TECHNOLOGY

MTL's activities supporting Canada's foundry industry is concentrated mainly in three areas. First, are short-term projects relating to immediate problems encountered by foundries. Second, is the upgrading of the technological capability of Canadian foundries, effected through regional workshops and projects such as Electric Furnace Cost Analysis, Real Time Process Control, and Green Sand Evaluation Studies. Third, is work concerned with the development of new techniques or processes that are deemed capable of giving a competitive edge to Canadian foundries. The projects on Vacuum Casting Processes, Gravity Permanent Mould Casting, and Zinc Aluminum Alloys come under this category.

DICK WARDA

Project Leader
Process Control
992-0949

AUTOMATED CASTING PROCESS

Work on low pressure disposable mould casting (LPDMC) has been restricted to the demonstration of the process to a Canadian automotive foundry using their foam patterns of specific engine components. The majority of effort has been concentrated on the further development of a vacuum pouring technique, an offshoot of the LPDMC process. This technique allows moulds to be poured using metal taken from below the molten surface of the furnace thereby minimizing dross or slag carry-over as well as decreasing reoxidation. Flanged pipe-junction castings weighing approximately 7 kg have been produced in both no-bake and green sand moulds using a specially designed vacuum flask. Alloys cast include aluminum, copper, grey iron and steel. Work will continue to establish the optimum casting parameters for the process.

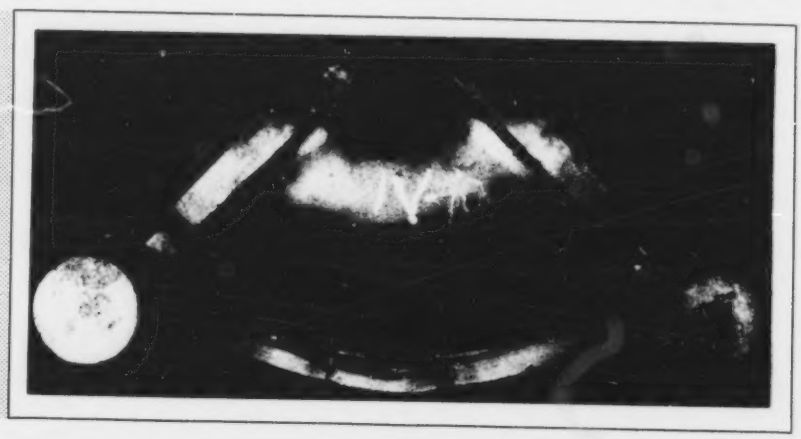
ELECTRIC FURNACE COST ANALYSES

The foundry cost control software has been completed and is in use by CANMET, a provincial utility company and a provincial research organization. The software has been used this past year to provide services to CANMET clients, and efforts have also been directed towards the writing of the necessary documentation in preparation for marketing the software, and making it more "user friendly".

REAL TIME PROCESS CONTROL

The necessary hardware and software has either been acquired or developed over the past year in preparation for use in the field. Arrangements have been made and appropriate sensors tested to take real time process

Plain carbon steel elbow made in green sand and vacuum poured.



measurements on a large commercial cupola as well as on a green sand moulding line. The data will be computer logged, and this information then analyzed, enabling the development of suitable control parameters for the process to permit the installation of automatic controls.

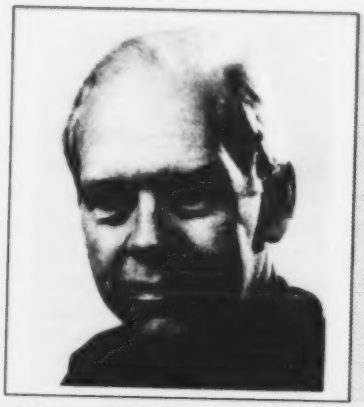
GREEN SAND EVALUATION STUDIES

A large database on sand quality control tests was obtained during the operation of the Mobile Foundry Service. One valuable result of this work has been a reassessment of the methylene blue test for measuring active clay contents in the sand. Current recommended procedures have been found to result in a significant fixed error in this measurement, and a new accurate methodology has been developed to overcome this problem.

GRAVITY PERMANENT MOULD CASTING

Contracted work on the mathematical modelling of heat flow in permanent moulds has been completed, yielding the capability of determining the rate of solidification of 2-D and simple 3-D shapes in metal moulds. The stresses developed in the metal mould due to thermal gradients can also be determined. This will assist in the future development of improved mould design in order to increase service life.

Thermal fatigue tests of candidate mould materials have also been concluded and indicate, in general, that unalloyed grey iron is as good as, or better than, ductile, C.G., or alloy irons. The use of water-cooled aluminum moulds has also progressed , and satisfactory grey and ductile iron castings have been made.



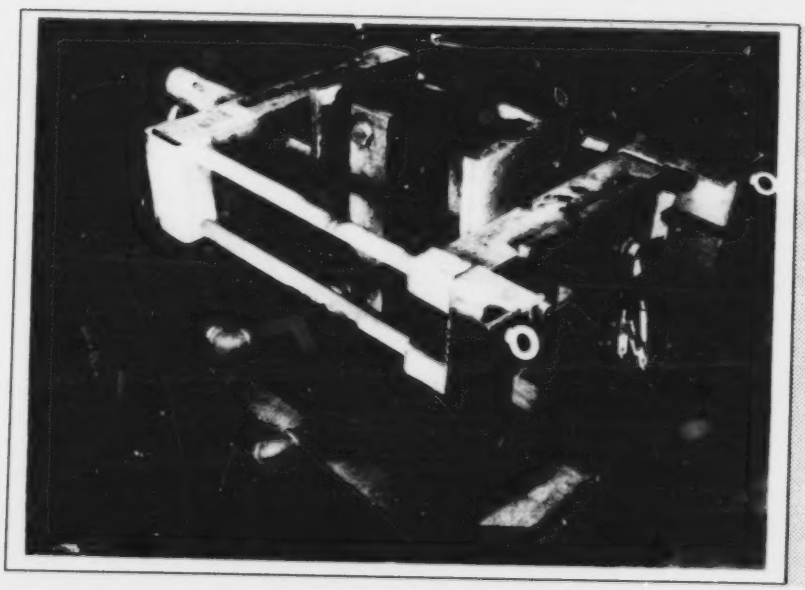
KEITH DAVIS

Project Leader
Process
Development
992-5096

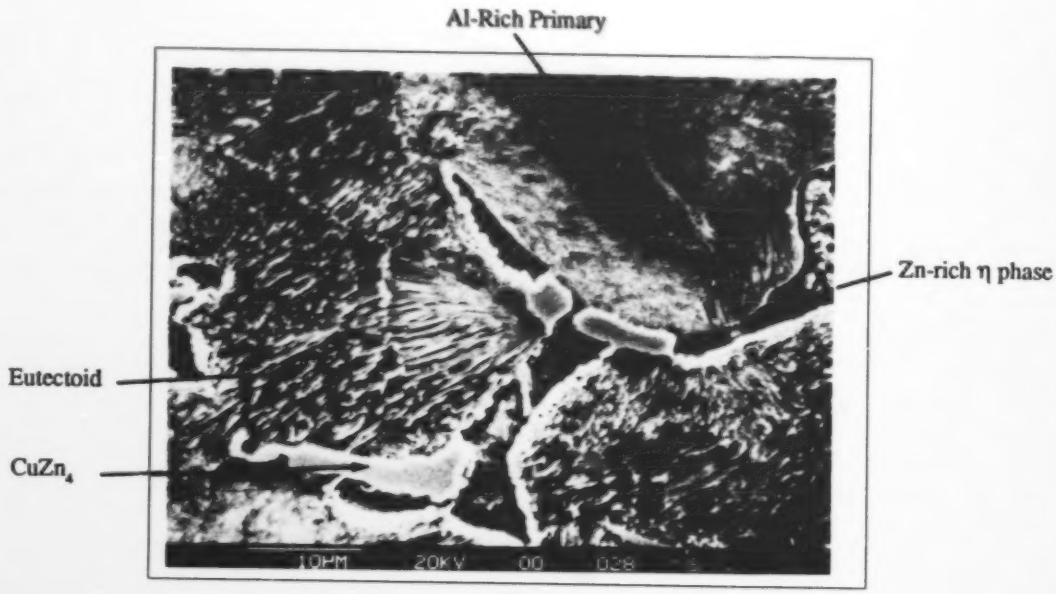
This project is to be expanded into copper-base alloys using a commercial permanent mould gravity casting machine to provide technical support for foundries introducing the permanent moulding of brass and bronze parts.

AUSTEMPERED DUCTILE IRON

The production and heat treatment of test castings has been completed, and test bars are currently being processed. Preliminary indications are that the levels of residuals under investigation (0.02% Sb, 0.04% V, 0.05% Cr and 0.03% Ti) have no significant detrimental effects on the heat treating characteristics or the mechanical properties of the alloys.



Water-cooled aluminum mould used to produce grey iron, ductile iron and steel castings.



Photomicrograph of a Zn-27% Al cast alloy showing the various phases present in this material. These alloys are used for sand and die casting applications eg. ring gears, marine electrical couplers etc.

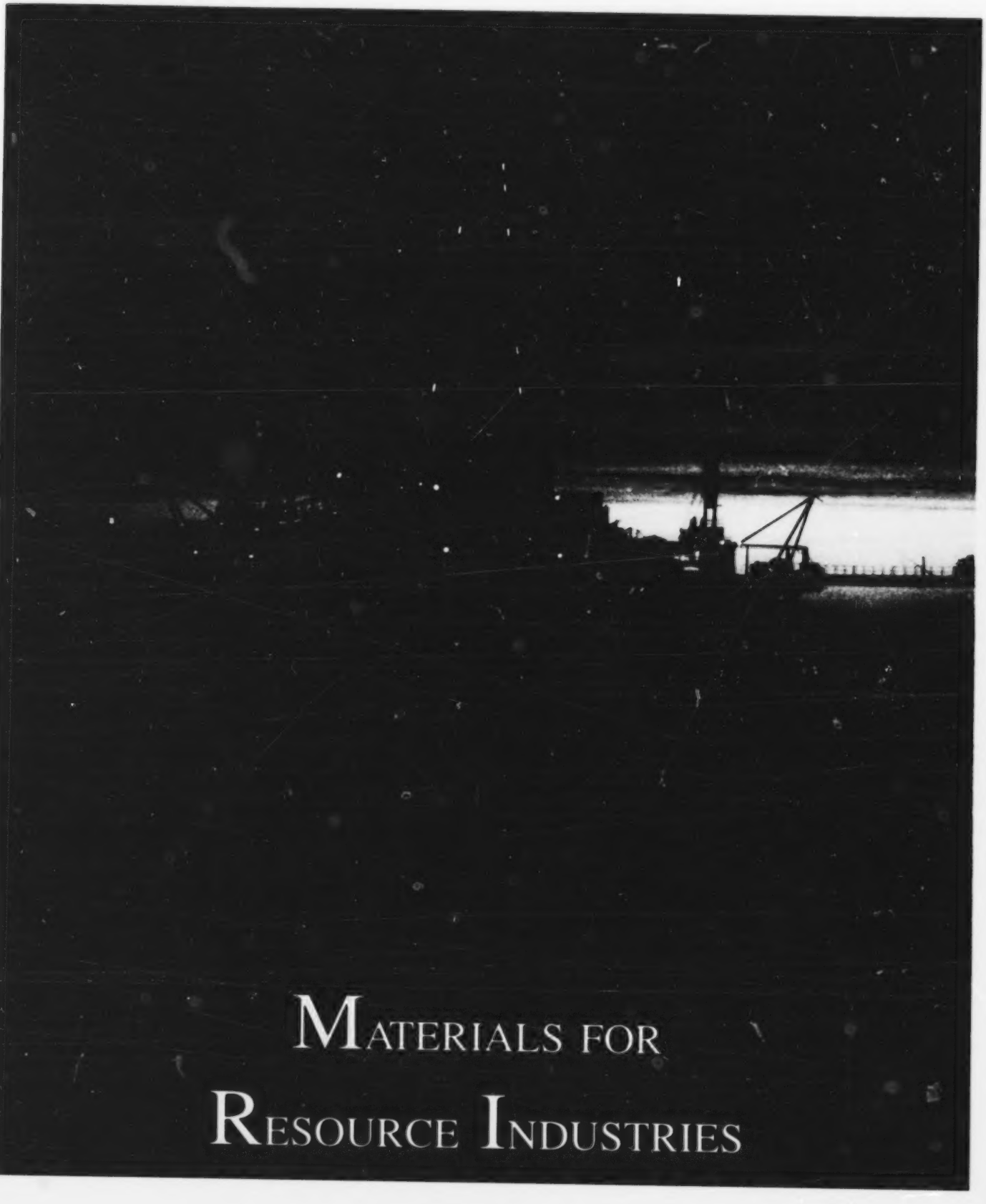
ZINC-ALUMINUM ALLOYS

Past work has shown that the addition of Sr or Ca to Zn-27% Al alloys can eliminate underside shrinkage defects, and that the Sr additions produced no deterioration in corrosion resistance in samples exposed to steam. This year, it has been shown that, as for Sr, Ca has no deleterious effect on resistance to steam corrosion in these alloys. A summary report on this completed project is in press.

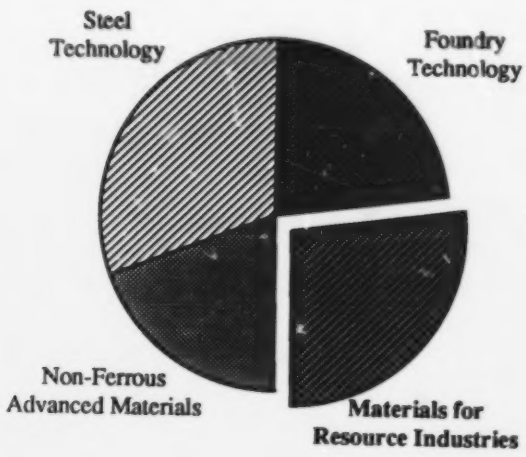
ANTIMONY IN HIGH-LEADED TIN BRONZES

Alloy C94100 containing 15-22% Pb, 4.5-6.5% Sn, 1% Zn and the balance Cu is used for cast locomotive journal bearings. Antimony contamination of the alloy results from the residual babbitt lining in the remelted scrap. The effect of antimony on mechanical properties was evaluated by increasing its content to levels considerably higher than the ASTM specified maximum of 0.80%. Antimony additions decreased tensile elongation from 17% at 0% Sb to about 5% at 2% Sb.

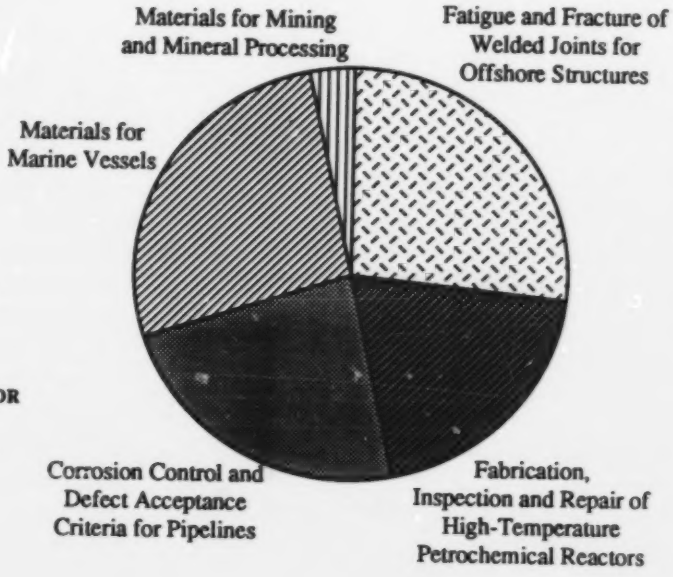
Attempts were also made to remove the antimony from the melt by additions of Mg, Mg + Sr, Ca, Mg + Ca, Ni + Mn and by injection of soda ash. None of these were successful and all resulted in a general deterioration of the mechanical properties of the alloy.



MATERIALS FOR RESOURCE INDUSTRIES



MATERIALS FOR RESOURCE INDUSTRIES PERSON YEAR ALLOCATION BY PROJECT AREA


Materials for Mining and Mineral Processing
Fatigue and Fracture of Welded Joints for Offshore Structures
Materials for Marine Vessels
Corrosion Control and Defect Acceptance Criteria for Pipelines
Fabrication, Inspection and Repair of High-Temperature Petrochemical Reactors

FATIGUE AND FRACTURE OF WELDED JOINTS FOR OFFSHORE STRUCTURES

* Fracture of Welded Joints
* Fatigue of Welded Structures
* Nondestructive Evaluation and Structural Monitoring

FABRICATION, INSPECTION AND REPAIR OF HIGH-TEMPERATURE PETROCHEMICAL REACTORS

CORROSION CONTROL AND DEFECT ACCEPTANCE CRITERIA FOR PIPELINES

* Hydrogen Damage and Corrosion
* Mechanical Damage
* ERW Weld Imperfections

MATERIALS FOR MARINE VESSELS

* Development of Welding Procedures for Marine Materials
* Weld Corrosion
* Fracture Control

MATERIALS FOR MINING AND MINERAL PROCESSING

JIM MCGRATH (LEFT)
992-3916

BILL TYSON (RIGHT)
992-9573

MANAGERS
MATERIALS FOR RESOURCE INDUSTRIES

MATERIALS FOR RESOURCE INDUSTRIES

The construction and maintenance of structures for resource production and transport in Canada's harsh climate requires technologies for welding and fabrication, for minimizing degradation in service, and for avoiding fracture. MTL work in this area can be described under five headings related to the industrial sectors involved.

FATIGUE AND FRACTURE OF WELDED JOINTS FOR OFFSHORE STRUCTURES

The overall objective of this program is to develop and evaluate technologies for fabricating and ensuring the safe operation of offshore production platforms in the harsh environments of Canada's East Coast and Arctic regions: specifically, to increase the fatigue and fracture resistance of welded joints through improved welding consumables, welding procedures, joint design and nondestructive evaluation.

FRACTURE OF WELDED JOINTS

The first phase of this project, the evaluation of over 40 currently available welding consumables for the shielded-metal-arc (SMA), flux-cored-arc (FCA) and submerged-arc (SA) welding processes has been completed. A detailed study on the scatter in crack tip opening displacement (CTOD) test results and comparison with Charpy test data for the same welds has resulted in the development of Charpy - CTOD correlations for -10°C and -30°C. This work has been used in the formulation of weld metal toughness requirements for the new CSA standard for Steel Fixed Offshore Structures (S473); MTL staff are writing major sections of the materials, toughness and welding clauses for S473. Investigation of the effects of heat input and nickel content on the M-A phase produced in SMA welds is continuing.

MAC BRAID

Project Leader
Fatigue and Fracture of Welded Joints
992-6400

Work continues in three external contracts aimed at future commercial development of welding consumables for optimum weld fracture toughness properties. Contract work has been completed on a study of inclusion effects on SMA weld metal toughness as well as surface tension and slag-metal reaction effects in FCAW consumables. Further work in this area is planned. Also, a new project on the pulsed gas-metal-arc welding (pulsed GMAW) process has been initiated to investigate fusion characteristics in the manual (semi-automatic) mode of operation. Wire and gas combinations developed in previous studies, as well as commercial consumables, will be used. The objective will be the elimination of lack-of-fusion defects to allow fabricators to take full advantage of the higher productivity and improved properties of the pulsed GMAW process.

FATIGUE OF WELDED STRUCTURES

The first phase of this project, examining adverse effects of increasing section thickness and cold ocean environments, including several levels of cathodic protection, has been completed. Experiments were conducted on plate and large pipe-to-plate welded joints. A novel technique, based on fracture mechanics, for accurate prediction of crack propagation life was developed and verified by experiments. Results from the project are being used to improve the fatigue design criteria in the new CSA standard S473 through the introduction of a penalty on fatigue life for structures with cathodic protection (test results from the project have shown that cathodic protection does not enhance fatigue life) as well as design curves which correctly reflect the adverse effects of increasing section thickness. Collaboration with the national research programs of Norway and members of the European Coal and Steel Community is continuing to add to the overall database.

An exploratory evaluation of the beneficial effects of smaller attachment thickness and improved weld profile on the life of welded joints has been completed using welded T joints with 50 mm base plate and 50 mm and 25 mm attachment plates. The results have shown a beneficial effect on fatigue life of smaller attachment

thicknesses and the use of the improved AWS weld profile at longer fatigue lives. Further experiments are under way to reconcile the effects of section thickness and weld profile on the fatigue design rules in Canadian, European and American standards.

Work on the prediction of fatigue crack initiation life in welded joints using a local strain approach has been completed. A rationalization of the thickness effect in welded joints has been made by comparison with test results of plates with machined notches simulating the weld geometry. The theory was found to predict the experimental results provided the correct value of the stress concentration factor was used. Further work on fatigue crack initiation at welded joints is under way using a fracture mechanics approach.

The development of facilities for variable amplitude testing using COLOS (Common Load Sequence, a system developed in Europe to simulate North Sea wave loading) has been completed. The hardware and software for generating COLOS, controlling the testing machine and data acquisition, was developed by MDT Engineering Ltd. of Waterloo, Ontario.

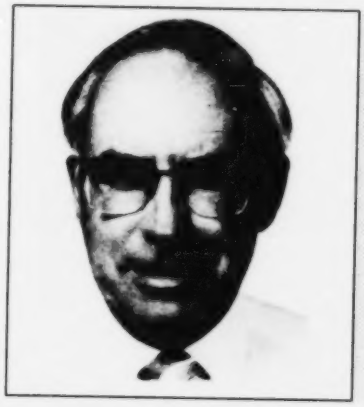
NONDESTRUCTIVE EVALUATION AND STRUCTURAL MONITORING

The objective of this project is to improve acoustical imaging for better characterization of defects by ultrasonic testing. Ultrasonic signals scattered from a flaw contain more information than is usually exploited. Mode-converted waves carry information that can be used in NDE of materials. A method which employs both longitudinal waves and mode-converted shear waves scattered from a flaw has been used to reconstruct the image of a flaw (a 5 mm diameter side-drilled hole). This provides a simple method for acoustical imaging; however, mode-converted waves are usually weak, making accurate measurements of their travel time difficult. Also, if more than one flaw is present, there is currently no method of determining the difference between a mode converted shear wave and a signal from another flaw.

Frequency minima obtained from spectral analysis could be used to characterize the shape, size and orientation of defects. Equations have been derived for flat circular voids using radiation field theory based on Huyghen's principle. Computer polar plots were drawn from the sound pressure profile of the scattered signal for different orientations of the scatterers (defects). Experimental spectral data from a 4 mm diameter flat-bottom hole agree well with the results of theoretical calculation.

FABRICATION, INSPECTION AND REPAIR OF HIGH-TEMPERATURE PETROCHEMICAL REACTORS

The objective of this project is to develop and evaluate technologies for the fabrication, corrosion control, inspection and repair of high-temperature reactor vessels in support of industrial initiatives for heavy oil and bitumen upgrading and coal conversion.



JIM MCGRATH

Project Leader
Fabrication, Inspection and Repair of High-Temperature Petrochemical Reactors
992-3916

In the development of welding processes for the fabrication of reactor vessels, an external contract has been completed on the application of the submerged-arc narrow-gap welding process for shop fabrication of heavy-wall Cr/Mo steel pressure vessels. Circumferential seam welds were made in cylinders (1800 mm ID x 1200 mm long x 200 mm wall thickness) of 2.25 Cr-1 Mo steel. The welds met required strength and notch toughness properties. The development and evaluation of weld overlay surfacing techniques is progressing through in-house and contract activities. The metallurgical characteristics (amount of dilution with the base metal, grain size of the austenitic microstructure, amount of ferrite and martensite constituents) of two-layer overlays (type 309L and type 347 stainless steel) deposited by the electroslag process have been evaluated. The ultimate goal is to deposit a single layer of type 347 to provide adequate corrosion resistance. Contract activities have concentrated on the development of shop capability using both the submerged-arc and electroslag-strip overlay techniques.

Fluidized bed combustion (FBC) is being utilized increasingly to burn sulphur-containing and low-grade fossil fuels such as coals, oil shales and coal-oil mixtures, placing severe performance burdens on heat exchanger tubes and bed supports. A materials evaluation program, carried out jointly by CANMET, Nova Scotia Power Corporation and Combustion Engineering Canada, has identified a corrosion-wear degradation mechanism of candidate alloys in atmospheric FBCs.

The total metal wastages as a function of alloy composition, temperature, and bed location have been reported and indicate a significant contribution from abrasion and from erosion. The table below lists the maximum observed attack rates of the various alloys which were included in three probes in the Point Tupper FBC bubbling bed. A, B and D Probes operated in the temperature regimes 400-570°C, 550-700°C and 850°C (bed temperature) respectively.

Maximum rates of attack (μm/a) of candidate alloys exposed in the Point Tupper atmospheric FBC.

Alloy	A Probes	B Probes	D Probes
A1	4700	—	—
T11	2500	—	—
T22	2900	—	—
T91	850	2000	—
304H	1200	700	—
347H	—	750	3700
310	—	720	1050
800H	—	1300	perforated
HK40	—	—	3000
253MA	—	—	5750

The work on inspection of pressure vessels has concentrated on the development of a commercially viable multi-transducer ultrasonic system for detecting and sizing defects. Two scanning bridges were built. Each scanner is capable of x, y, z and rotational movement. Absolute encoders were installed for both scanning bridges. An IBM-compatible computer was used to control both scanning bridges as well as to collect data. The two scanning bridges will allow two separate transducers to move independently of each other. This will enable one transducer to be used as a transmitter and the other as a receiver, enhancing the signal-to-noise ratio. Signal processing was performed on the raw data to provide images of defects. A 3-D image of a defect can be displayed and the dimensions of the defect can be determined.

Several meetings were held with industries representing the operation, design and fabrication of petrochemical plants to define a cooperative program on weld repair of petrochemical plant structures. Two programs were defined with the following objectives: (1) the demonstration of Engineering Critical Assessment (ECA) as a viable method for making a decision to perform weld repairs on defects, and (2) development and evaluation of weld repair procedures for Cr/Mo steels. It is intended that work in this project will be initiated in FY 88/89.

CORROSION CONTROL AND DEFECT ACCEPTANCE CRITERIA FOR PIPELINES

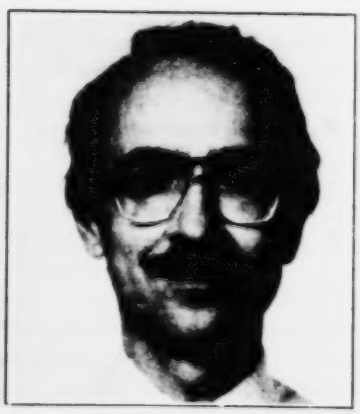
Drawing on the extensive pipeline R & D conducted at MTL in the 1970's and 1980's, three current projects in this area address:

1. hydrogen damage and corrosion,
2. mechanical damage, and
3. ERW weld imperfections.

HYDROGEN DAMAGE AND CORROSION

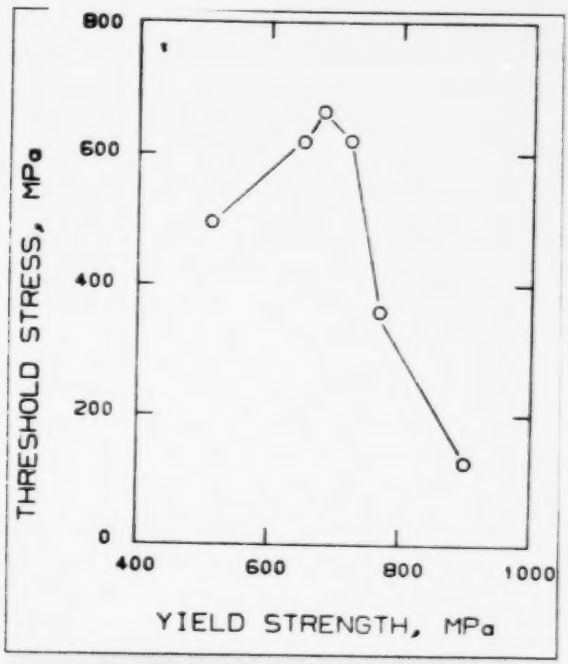
Hydrogen damage is of current interest with the trend in the oil and gas industry to develop sour (i.e. containing H_2S) wells. Combinations of CO_2, H_2S, and moisture produce highly corrosive environments. Sulphide stress cracking (SSC) and stepwise cracking (SWC) are two types of hydrogen damage that may result from these very corrosive conditions. During 1987/88, effort continued on a project to establish the variation of threshold stress for SSC with yield strength for 4130-type oil country tubular goods (OCTG) steel. Work is being carried out to improve the resistance to SSC at a strength level of 120 ksi (840 MPa).

Ultrasonic C-scanning was shown to be an effective method for detecting SWC and for locating cracks (detection limit ~0.03 mm) in coupons that had been exposed to an acidic saline H_2S-saturated solution. For clean steels, banded microstructures were shown to be detrimental to SWC resistance. In a series of 19 linepipe steels that were evaluated for resistance to hydrogen-induced damage, five steels had threshold hydrogen concentrations greater than 1.0 mL H_2/100 g steel, indicating good resistance to SWC.



WINSTON REVIE

Project Leader
Corrosion Control and Defect Acceptance Criteria for Pipelines
992-1703



Threshold stress for sulphide stress cracking of an API C-90 steel heat treated to six different strength levels

A detailed review of techniques used to monitor localized corrosion in sour gas pipelines showed the importance of critical pitting potential and the applicability of electrochemical noise and AC impedance techniques in assessing the extent of pitting corrosion. Data obtained in preliminary experiments showed good correlation between noise amplitude and pit depths. It is planned to extend this experimental approach to sour gas pipelines in the field

MECHANICAL DAMAGE

Work was completed during 1987/88 on the assessment of analytical mechanical models to predict the effect of external damage (dents, gouges, and gouges in dents) on the failure pressure of linepipe. Comparison of predictions with experimental results generated at MTL showed that, while acceptable understanding exists for separate dents and gouges, there is no broadly applicable theory for the behaviour of gouges in dents. Results have been correlated using an empirical parameter combining relevant variables (essentially the size of dent and gouge, and pipe toughness), and more work is planned to develop a rational basis for the correlation.

ERW WELD IMPERFECTIONS

The effect of bond-line weld imperfections in pipe made using the ERW process on the failure stress and sulphide stress cracking resistance is being studied at MTL in collaboration with several pipe producers and users. SWC and SSC tests, as well as tensile tests, have been carried out on samples of pipe containing defects intentionally introduced into the weld during manufacture. SWC resistance was good for weld coupons with and without defects. Longitudinal weld tensile specimens were susceptible to SSC, but the defects did not affect the degree of susceptibility. The fracture stress was reduced proportionally to the reduction in load-bearing area, indicating little notch sensitivity of the bond line

MATERIALS FOR MARINE VESSELS

The objective of this work is to assist in the provision of economical and environmentally safe marine vessels with particular attention to Canadian conditions. These conditions include a manufacturing base characterized by relatively small fabricating yards, and service at low temperatures under impact with ice in a severely corrosive environment. Steels of increasing strength and thickness are being considered for ships to operate in the high Arctic, for example, the "Polar 8" icebreaker, placing heavy demand on fracture control and material selection.

Work is being performed in collaboration with regulators [e.g., Canadian Coast Guard, which administers the Canadian Arctic Shipping Pollution Prevention Regulations (CASPPR)], steelmakers and fabricators (e.g.,

Conceptual design of the "Polar 8" icebreaker

BILL TYSON

Project Leader
Materials for
Marine Vessels
992-9573

Stelco and Algoma, Canadian Liquid Air and Lincoln Electric), within three projects oriented toward fabrication, corrosion prevention, and avoidance of brittle fracture respectively.

DEVELOPMENT OF WELDING PROCEDURES FOR MARINE MATERIALS

The aim of the marine materials welding project is to improve Canadian shipyard expertise in fabrication and welding technology, particularly for the anticipated DND submarine acquisition program, the continuing Frigate program, Coast Guard ice breakers, and other marine structures.

The present project has three primary objectives:

(i) development of submerged-arc welding (SAW) procedures for high-strength steels in critical applications,

(ii) development of gas-metal-arc welding (GMAW) for critical applications requiring out-of-position capabilities, and

(iii) identification and quantification of the factors controlling the microstructure/property relationships of high-strength submerged-arc and gas-metal-arc weld metals.

The development of SAW procedures has focussed on the joining of HY80, HY100 conventional high-strength steels and the new HSLA80 and 100 low-alloyed steels.

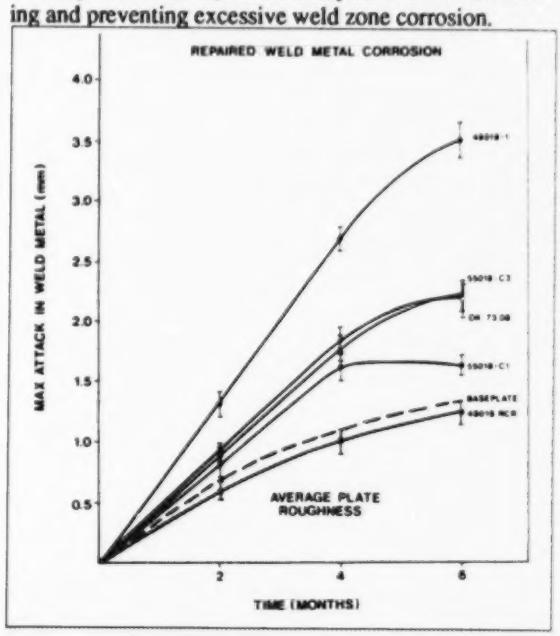
The work of the evaluation of HY80 weldments was completed in 1987. Using commercially available welding consumables, the strength and notch toughness property requirements for weld metal (47 J at -50°C and 81 J at 18°C) were achieved. It was noted that liquation cracking takes place in the CGHAZ if sulphur levels are above 0.005 wt %. The work on SAW HY100 weldments indicated that precautions must be taken (preheat and post-weld hydrogen removal) to prevent hydrogen-assisted cracking in the weld metal.

There was no problem in achieving sound SA welds meeting the property requirements for HSLA80 steel. The work on HSLA100 has just begun. Since this is an experimental steel, welding consumables are not commercially available. Development of SA and GMA welding wires is being carried out in-house. The equipment for GMAW of the high-strength steels is now operational. Work will commence in 1988 to develop welding procedures for HSLA80 and HSLA100 steels.

The relationship between microstructure and notch toughness for the simulated CGHAZ was studied for HSLA80 steel. The microstructure was determined as a function of cooling time by constructing a CCT diagram based on cooling times representative of SAW. The notch toughness requirements (same as above for HY80 weldments) were only met for simulated CGHAZ microstructures with $\Delta t_{800\text{-}500} \leq 11$ s (2 kJ/mm). The work on simulated CGHAZ microstructure/mechanical property relationships for HSLA180 has begun.

WELD CORROSION

MTL owns and operates a tank testing facility unique to Canada for studying seawater corrosion of plate undergoing abrasion in simulated ice, and has several projects under way involving the Canadian Coast Guard (CCG) and the private sector (steelmakers and producers of welding consumables) with the objective of understanding and preventing excessive weld zone corrosion.



Rate of corrosion of different SMAW electrodes used for weld repair

On the basis of work on weld repair samples, recommended procedures for weld repair have been issued to the CCG fleet. Weldments from the MV Arctic have been evaluated, and a project on arc sprayed coatings for shipbuilding applications has been initiated.

FRACTURE CONTROL

In support of casualty investigations by the CCG, mechanical properties of steel plate including strength and toughness have been measured. These data add to those already accumulated at MTL on the properties of typical ship plate, and provide background information for the development of fracture control specifications such as those in the CASPPR (Canadian Arctic Shipping Pollution Prevention Regulations).

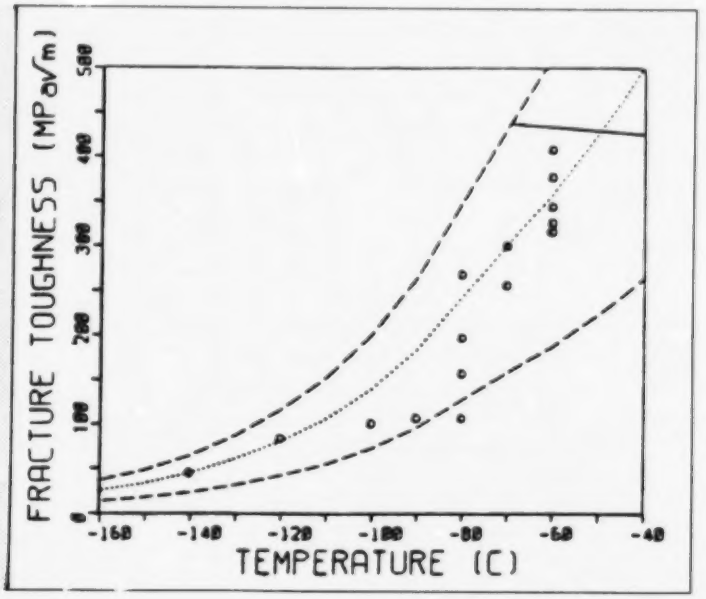
A theory of brittle fracture based on a "weakest link" model has been developed, resulting in an analytical relation between fracture probability, stress intensity, plate thickness, and yield strength. Predictions of the model have been tested successfully with measurements made on a Canadian offshore-grade steel over a range of temperatures (from room temperature down to -140°C) and strain rates (from 2×10^{-5} s^{-1} to 20 s^{-1}). In collaboration with the CCG and private industry, a probabilistic approach to fracture control is being developed to take into account the effects of typical steel properties and service conditions, notably temperature and strain rate, with the objective of setting toughness criteria that will be adequate but not excessively conservative.

BERNARD FAUCHER

Project Leader
Materials for Mining and Mineral Processing
992-9831

MATERIALS FOR MINING AND MINERAL PROCESSING

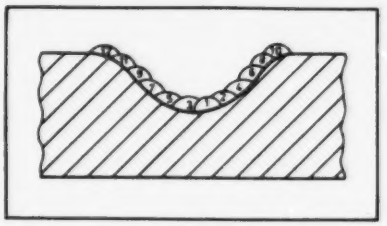
Contracts have been issued to study the properties of tungsten carbide tool bits, and to determine procedures for repair welding of cast iron mining equipment. Results for repair welding are very encouraging, and were presented at the October 1987 meeting of the Maintenance Division of the CIM in North Bay. The need for a research program on the hard-facing of mining equipment to combat wear is being evaluated. Other CANMET research includes the NDT of wire rope, the "CANMETCOAT" hardfacing process, and the development of rock bolts with good corrosion resistance in aggressive mine waters. Increased activity in solution of specific materials problems of the mining



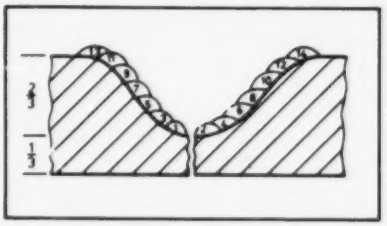
Temperature dependence of the cleavage fracture toughness for 50 mm thick specimens. The curves correspond to 50% (dotted) or 5 and 95% (dashed) failure probability, as calculated from an analytical model of brittle fracture

industry is planned, including renewed work on corrosion based on CANMET results of the 1970's and early 1980's on wear of grinding media, erosion/corrosion, and corrosion inhibition in ball mills.

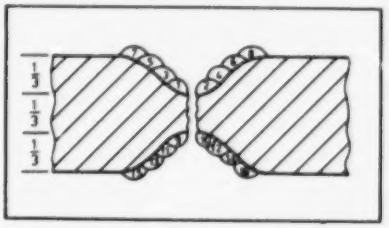
Butter layer placement for weld repair of cast iron equipment



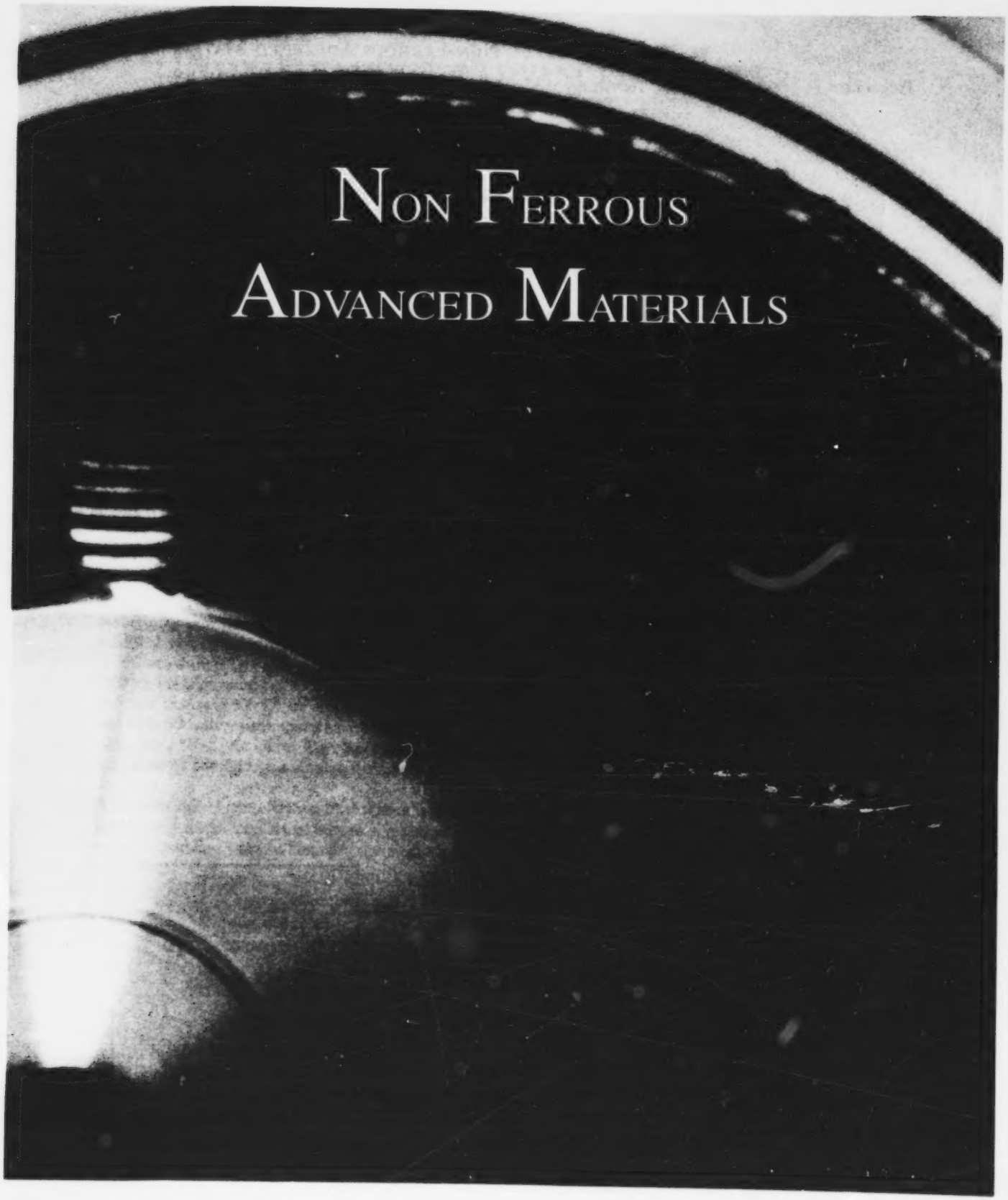
Shape of groove after defect removal and deposition sequence of butter layer.



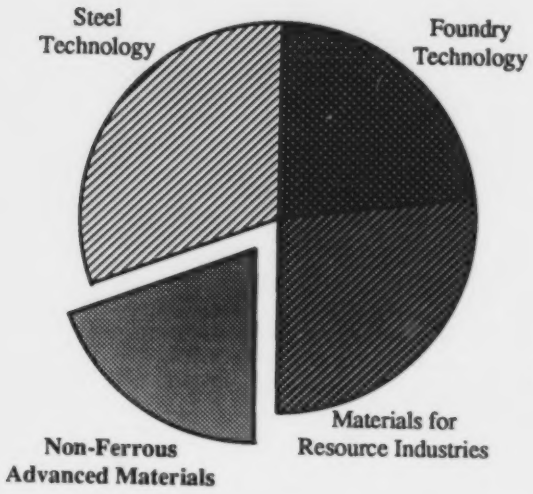
Repair of cracked casting from one side. Butter layers do not bridge crack.



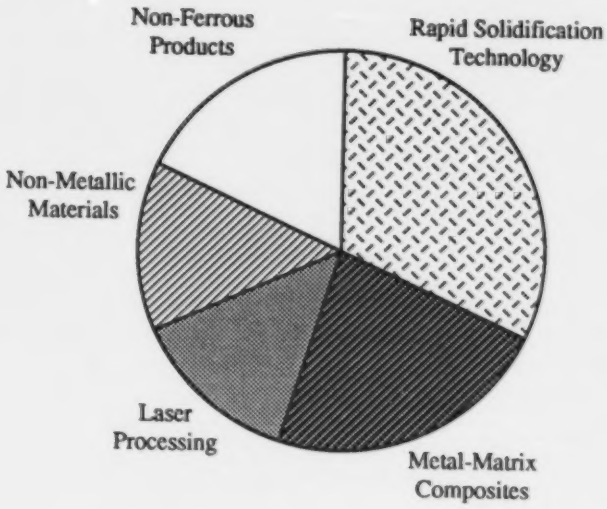
Repair of cracked casting from both sides.



Non Ferrous Advanced Materials



NON-FERROUS ADVANCED MATERIALS PERSON YEAR ALLOCATION BY PROJECT AREA



RAPID SOLIDIFICATION TECHNOLOGY

* Corrosion Resistant Al-Bronzes
* Near-Net Shape Casting
* Fe-Nd-B Permanent Magnets
* Amorphous Coatings

METAL-MATRIX COMPOSITES

* Production of MMCs
* Character of MMCs

LASER PROCESSING

* Laser Surface Hardening
* Laser Welding
* Laser Surface Modification and Alloying

NON-METALLIC MATERIALS

* Structural Materials
* Functional Materials

NON-FERROUS PRODUCTS

LAURIE COLLINS (LEFT)
992-1488

MAHI SAHOO (RIGHT)
992-5475

MANAGERS
NON-FERROUS
ADVANCED MATERIALS

NON-FERROUS ADVANCED MATERIALS

The current world-wide development of advanced materials and implementation of new processing technologies to produce high value-added products now threatens the markets of traditional metal producers. To remain competitive, Canadian industry must seek to identify opportunities to develop and apply new technologies to produce improved products and/or improve processing efficiency. MTL's Non-Ferrous Advanced Materials program has been established to assist Canadian industry in this process. At present, the program encompasses five project areas.

RAPID SOLIDIFICATION TECHNOLOGY (RST)

The RST project is directed into two areas: the development and implementation of RS processes and the development of alloys which utilize RS processing to achieve improved properties.

To obtain cooling rates in excess of 10^4 K/s, RS materials must be produced in the form of thin strip or particles, which have limited engineering application. Processing work at MTL has focussed on techniques for production of materials suitable for consolidation into bulk forms, and on consolidation processes. During 1987/88, work was initiated at the request of an industrial client on the **direct casting of particulates**. In preliminary work on low melting point materials, a modified melt spinning technique was used successfully to produce Sn and Zn flake. For **consolidation**, a 200 ton press pressure has been modified to extrude at temperatures up to 500°C. To date, cold-compacted Cu and Al-bronze alloy particulates have been successfully extruded at 500 C. In future, this equipment will be used to study consolidation in specific alloy systems.

A disadvantage of consolidation by extrusion is the requirement for prolonged exposure to high temperatures - a condition which is normally detrimental to the properties of RS materials. **Explosive compaction** avoids this problem. This process has been examined under a contract with Limpact Industries. In this study, an effort was made to optimize the compaction process. Iron compacts were successfully produced with good bonding and high density (>98% of theoretical). However, it is clear that the processing window, which produces good bonding while minimizing the detrimental effects of reflected shock waves, is very narrow and is material dependent. Thus, the process must be optimized for each alloy to be consolidated.

LAURIE COLLINS

Project Leader
RST
992-1488

Coating materials with highly corrosion-resistant metallic glasses presents an exciting development opportunity. During 1987/88, a contracted research program was initiated at the University of Sherbrooke to examine the feasibility of producing an $Fe_{70}Cr_{10}P_{13}C_7$ **metallic glass coating by plasma deposition**. To date, amorphous coatings as thick as 120 µm have been prepared and corrosion tests are currently being conducted at MTL.

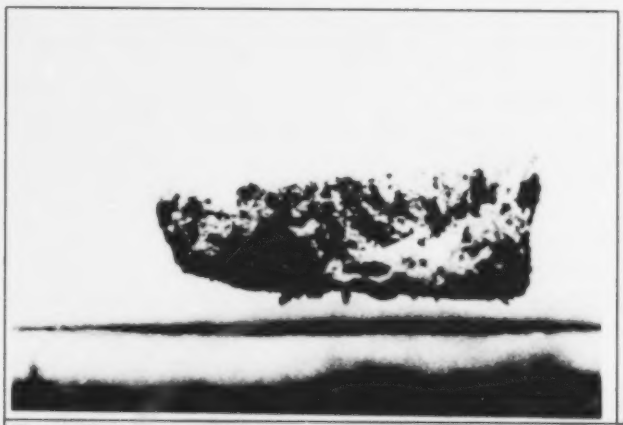
Rapid solidification may produce a number of microstructural modifications, including refined grain size, improved chemical homogeneity, extended solid solubility and formation of metastable phases, all of which can be utilized to develop materials with improved properties. A number of alloy development projects are underway which seek to apply these modifications in a beneficial manner. In an on-going project with DREA, it has been shown that the **solubility of Fe in Al-bronzes can be increased** from 3.5 to 9.0 wt % in melt-spun ribbons. The increased Fe solute content achieved in RS materials produces an order of magnitude improvement in corrosion resistance in a 3.5 wt % NaCl solution compared with sand-cast alloys of similar composition. At present, these RS materials are being consolidated by extrusion to determine if the enhanced properties can be retained in the consolidated material.

In a joint project with Noranda and IMRI, the feasibility of **direct casting Cu-Ni-Sn strip** has been examined, and, in particular, the effects of cooling rate on Sn segregation have been assessed. Although microsegregation cannot be eliminated even in 20 μm thick melt spun ribbons, the segregation pattern is significantly refined. As well, macrosegregation, which is a problem in continuous-cast plates, was not evident even in strip as thick as 1.5 mm. In further development work, 1.5 mm thick Cu-Ni-Sn strips, 15 cm wide, have been successfully cast by a single wheel casting process, and the microstructure and properties of these materials are being assessed.

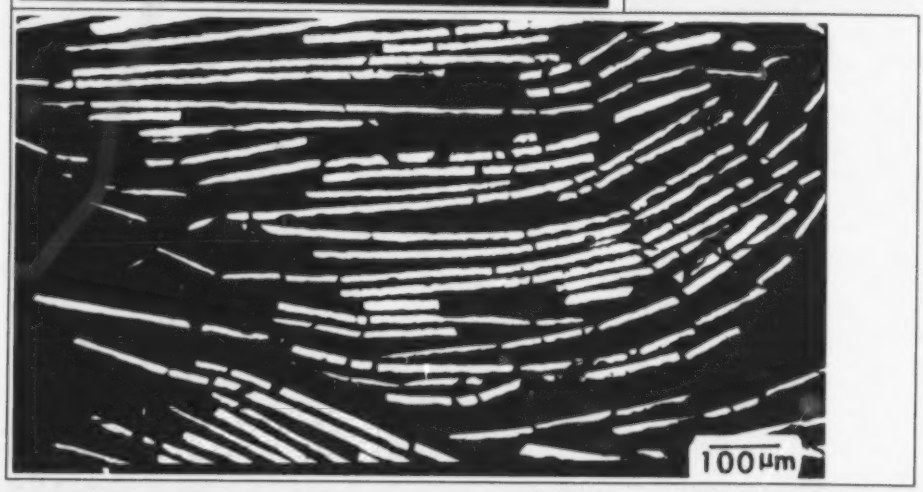
Work on **Fe-Nd-B permanent magnet alloys** seeks to establish the alloy and processing requirements for the production of high-quality magnets. Two alloys, the stoichiometric $Fe_{81}Nd_{13}B_6$ and $Fe_{77}Nd_{15}B_8$ have been selected for study. Techniques have been developed for alloying and melt spinning the alloys to produce rapidly solidified particulate. Bonded magnets, produced by embedding the particulate in a plastic matrix have a coercivity of 8.5 kOe. Studies have now been initiated on the fabrication of anisotropic magnet material. In a complementary project, being carried out with an industrial client, the effects of impurity elements on magnetic properties are being assessed. However, the inhomogeneous composition of the master Fe-Nd alloy supplied by the client has limited this study.

METAL-MATRIX COMPOSITES (MMCs)

It is now well recognized that the properties of an alloy, particularly elastic modulus, strength and wear resistance, often can be significantly improved by embedding ceramic particulates into the metal matrix. For this reason, the development of metal matrix composites (MMCs) has become a primary objective of many metals producers. The major problems to be overcome in the production of MMCs are identification of suitable reinforcing agents for various alloy systems, control of particulate/matrix interface reactions and development of uniform dispersions of particulates. The MTL program assists Canadian industry in resolving these problems. It was initiated in 1987/88, but will be significantly expanded in 1988/89 to meet industrial requirements.



Fe-Nd-B supermagnet levitated over ceramic superconductor.



Supermagnet is magnetic composite of $Fe_{77}Nd_{15}B_8$ in a plastic matrix.

JASON LO

MMCs
992-2669

During 1987/88, several attempts were made to produce a **dispersion of Mo_2C and Mo in pure copper** to obtain a composite casting with better wear resistance, improved ambient and high temperature mechanical properties while still maintaining the high conductivity of copper. Although partial success was achieved in producing a dispersion of Mo in a copper matrix, the resulting tensile properties are still in need of improvement.

A research contract to Hard Materials Research Ltd., Mississauga has produced a **market analysis of tungsten carbide products in Canada** and identified a trade balance of about one hundred million dollars per annum. In addition, a techno-economic evaluation of the possible return on investment (ROI) in increasing the value-added component of tungsten mining in Canada by fabrication of ammonium pyro-tungstate (APT), W powder, WC powder and pressed and sintered WC parts has been completed. This report identifies mining applications as an attractive market area and selects technologies for fabrication implementation. Software is included in the report to enable the reader to perform his own "what if" analyses by varying APT prices, production capacity of plant, location of plant, etc, to examine the effects of input data on return on investment.

Applied research under the contract with Hard Materials Research Ltd., aims to develop improved binders for WC which will impart enhanced corrosion and creep resistance. **Nickel-base hard metal binders** have been prepared with varying additions of aluminum and chromium. Immersion tests in dilute acid or NaCl solutions reveal the superiority of Ni-bonded materials in comparison to Co-bonded material in tests at room temperature and 100°C. The addition of Cr has a small beneficial effect, but aluminum appeared to have no effect on corrosion behaviour. The tendency of chromium to hinder the attainment of full densification in hard metal has been investigated by dilatometry and resistivity measurements at MTL. The existence of a liquid phase has been indicated at much lower temperatures in the presence of chromium. **Hard metals with improved creep resistance** and being developed by employing either precipitation hardening or solid solution strengthening of the binder phase. In nickel-bonded material with aluminum additive, sintering conditions and aging treatments are being examined to determine the conditions giving the optimum γ' precipitation hardening.

LASER PROCESSING

At present, this project focuses on the use of lasers for welding and surface modification. Work is carried out on a collaborative basis utilizing the 2.5 kW CO_2 laser in the Manufacturing Technology Centre at the National Research Council, Canada (NRCC).

A two-year project, being carried out in participation with Alcan and the Welding Institute of Canada, examines the **use of medium power lasers to weld 3 mm thick aluminum plate**. Poor heat transfer from the beam to the workpiece, because of the high reflectivity of aluminum, limits penetration depth. Various surface treatments have been examined to improve coupling and thereby produce deeper and more uniform welds with reduced porosity. To date, full penetration at a scan rate of 150 cm/min of 3 mm thick 1100 series plate has been achieved when a prior clear surface anodizing treatment is employed. Future work will examine the use of other surface treatments, and welding of other aluminum alloys.

Laser surface hardening of Javelin grade drill rod is being compared to the hardening achieved by both induction hardening and carburising in a project with

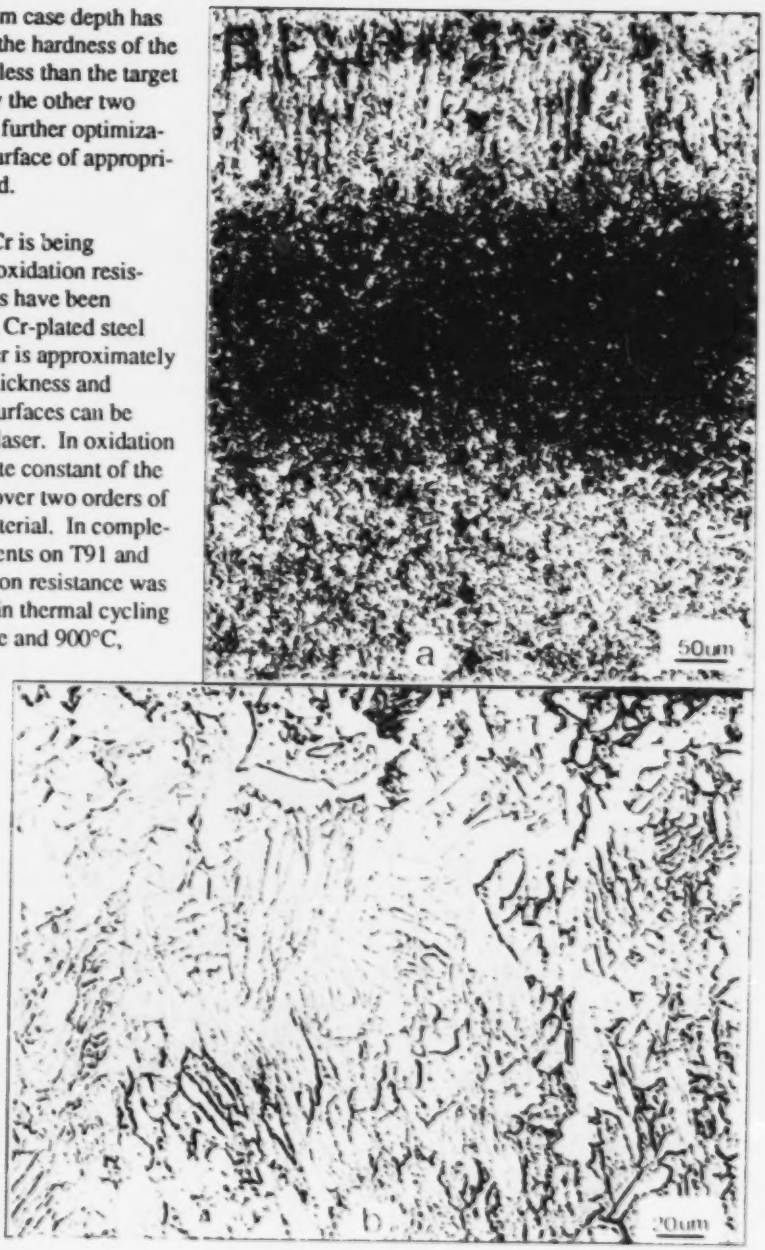
LOUISE MALLORY

Laser Welding
992-7906

seconded from
Welding Institute
of Canada

Boart Canada Inc. The necessary 1 mm case depth has been achieved by laser treatment, but the hardness of the laser treated surface has been slightly less than the target value of R_c 56 attained or exceeded by the other two treatments. It is anticipated that, with further optimization of the process, a laser hardened surface of appropriate hardness and depth can be achieved.

Laser surface alloying of steel with Cr is being investigated as a means of improving oxidation resistance. Chromium rich surface coatings have been applied to T91 steel by laser melting a Cr-plated steel surface. The laser-treated surface layer is approximately 200 µm thick, but is non-uniform in thickness and chemistry. The uniformity of treated surfaces can be improved by multiple passes with the laser. In oxidation tests at 900°C, the parabolic growth rate constant of the laser treated material was reduced by over two orders of magnitude compared with the base material. In complementary laser surface glazing experiments on T91 and 304H steel, no improvement in oxidation resistance was observed in laser treated material, but in thermal cycling experiments between room temperature and 900°C, spallation of the 304H was reduced by a factor of 7 by the laser surface treatment.

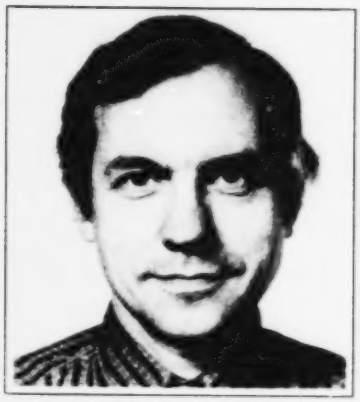


Microstructure of a chromium surface-enriched Fe-based alloy produced by laser surface alloying. The heat-affected-zone (intermediate, dark layer) is significantly harder than the substrate (T91) and the melted zone.

NON-METALLIC MATERIALS

The purpose of the non-metallic materials project is to apply unique MTL facilities and expertise in microanalysis and fracture mechanics to assist industry in characterizing microstructure and properties of microelectronic materials and advanced ceramics.

Several collaborative research projects directed toward **characterization of materials for the microelectronics industry** have been initiated with the National Research Council, Canada and Northern Telecom/Bell Northern Research. These involve the characterization of layered semiconductor materials grown at NRCC by molecular beam epitaxy and chemical vapour deposition. MTL's new secondary ion mass spectrometer (SIMS), installed in the summer of 1987, is particularly well suited to such studies.

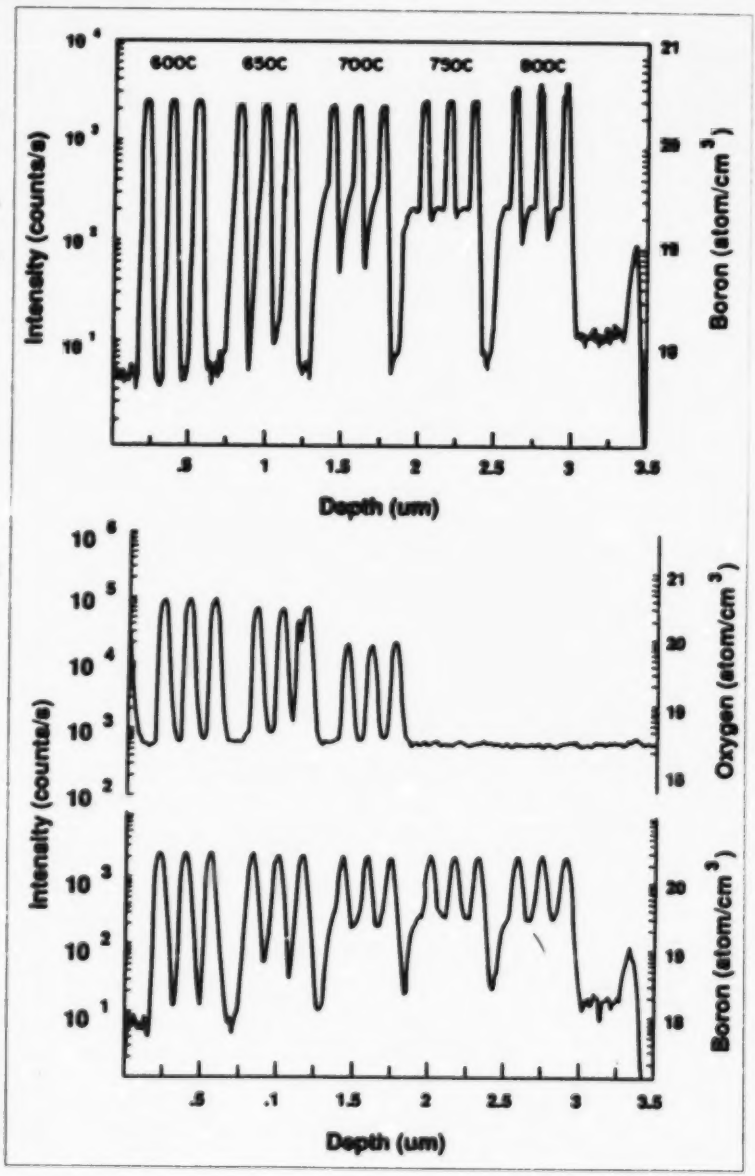


TOM MALIS

Project Leader
Non-Metallic Materials
992-2310

The areas of research currently under investigation by SIMS include boron segregation, clustering and redistribution during Si MBE growth, B and As doping of Si mesa structures, redistribution of doped layers in Si and Ge following oxidation or silicide growth, Mg doping of GaAs and $Ga_xIn_{1-x}As$, Ga leakage into CdTe layers grown on GaAs substrates and C incorporation into InSb grown by chemical vapour deposition on GaAs.

The most mature project under SIMS investigation concerns the **boron-redistribution in multilayer doping superlattices** as a function of growth temperature (550-800°C) and doping concentration (3×10^{18} - 3×10^{20} B/cm^3). It has been found that boron is carried forward into the intrinsic spacer layers during MBE growths at growth temperatures above 700°C when the doping level exceeds the solid solubility limit. At lower growth temperatures, oxygen is incorporated into the doped layers at concentrations nearing 100 times its normal solubility. The oxygen acts to inhibit the mobility, but not the electrical activity of the boron. Although the degree of oxygen incorporation, and its temperature dependence, can be understood on the basis of a simple thermodynamic model, its effect on boron redistribution is not yet understood.



SIMS depth profiles showing the boron and oxygen content in epitaxial layers grown at different temperatures by silicon molecular beam epitaxy at the NRCC.

In collaboration with Alcan Aluminum and McMaster University, a study on **microstructure-property relationships in modern industrial ceramics** was begun. With the assitance of a graduate student from McMaster, the first stage of this study centred around utilization of analytical electron microscopy (AEM) to provide chemical information on glassy intergranular films in sintered silicon nitride. The AEM methodology developed was used to monitor the crystallization of this

glass phase at elevated temperatures. This information will be correlated with mechanical property data in the second stage of the study. An upgrading of MTL facilities for preparation of test specimens and subsequent mechanical property determination has been initiated. An effort in **characterization of ceramic reinforcing fibres** for composite materials commenced with the secondment of a scientist from Ceramics Kingston to MTL. This work will be conducted in collaboration with the Ceramics Group of Mineral Sciences Laboratories (MSL).

TEM micrograph of (a) sintered silicon nitride at 100,000 X showing (b) an intergranular phase, identified by energy loss spectroscopy as $Si_2Y_2O_7$, which has crystallized in a fashion detrimental to mechanical properties.

MAHI SAHOO

Project Leader
Non-Ferrous Products
992-5475

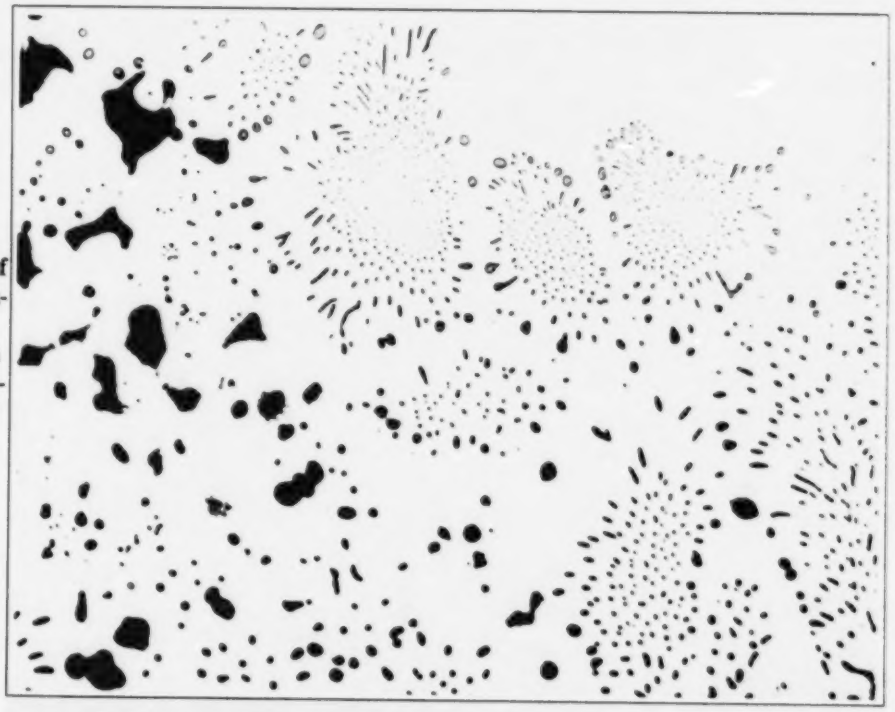
NON-FERROUS PRODUCTS

This project was initiated to provide assistance to Canadian non-ferrous industry in developing new products in areas not covered by other MTL projects.

Copper anodes are being examined which were supplied by the four mines participating in an investigation of the effects of anode impurities on the efficiency of electrodeposition and recovery from the process slimes. All the anodes had significant amounts of selenium. The Inco anode contained a high level of nickel, the Kidd Creek samples a high level of lead, the Noranda anode a significant amount of arsenic and antimony, and the Hudson's Bay anode the highest level of gold. Optical metallography of samples taken from various locations in the anodes has been completed, and the results of electron microprobe characterization of typical inclusions are being studied. This project is steered by a working group made up of representatives from the above mentioned mining companies as well as representatives from universities and CANMET.

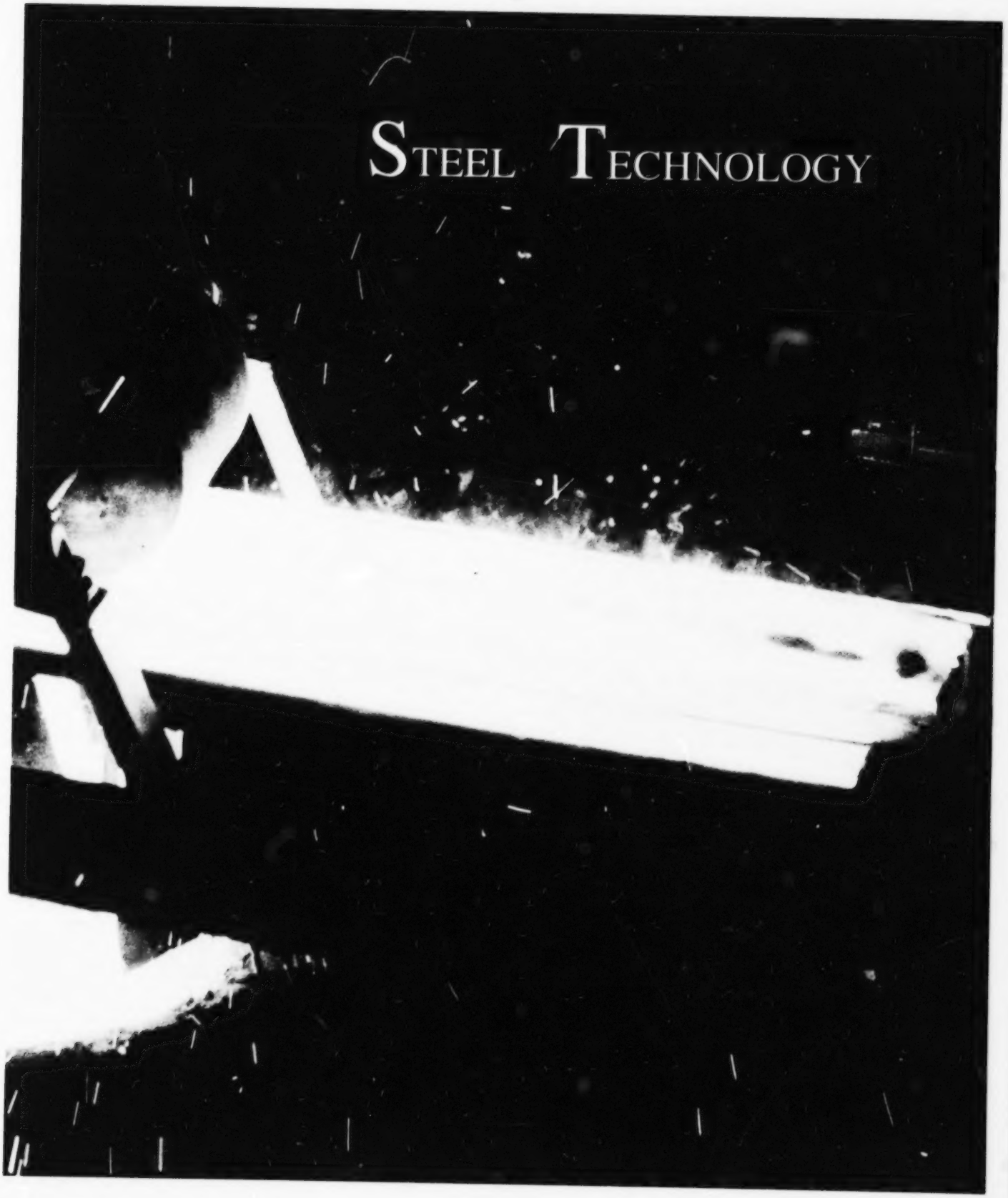
In cooperation with the U.S. Department of Energy, ductile billets of **nickel aluminide** have been produced using MTL's unique electroslag casting facilities. Those billets and the twin-roll cast strips supplied by Oak Ridge National Laboratory have been thermomechanically processed. The ambient and high temperature erosion behaviour of these sheets has been determined using CANMET's erosion tester. The results at two impingement angles (30 and 90°) show that, for any specimen condition (cold rolled or annealed), there is no significant difference in erosion rate of the alloys when tested under identical conditions.

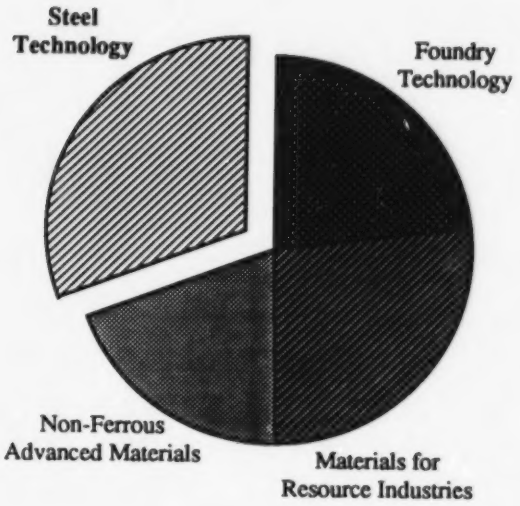
The **detection of lithium at grain boundaries** via electron energy loss spectroscopy (EELS) was carried out for both binary Al-Li and commercial Al-Li (#8090) alloys supplied by Alcan. EELS analysis of quenched, peak-aged and overaged specimens showed no detectable Li segregation, although grain boundary precipitates were analyzed at the expected Al:Li ratio of 2:1. Thus, either the segregation levels are below the EELS detectability limit, or the alloys are very inhomogeneous.



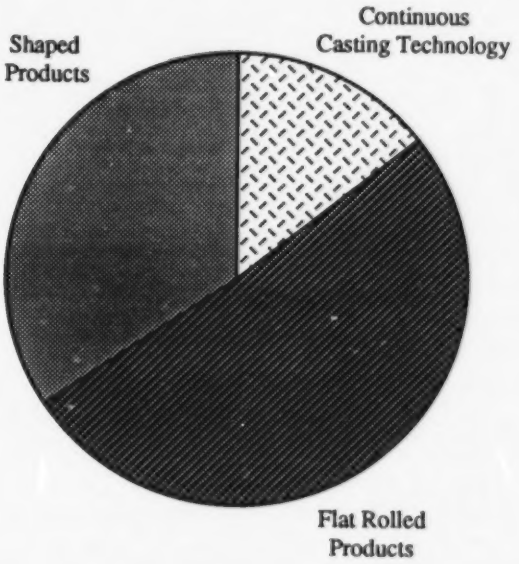
Copper oxide eutectic structure in Cu-anodes.

Steel Technology





STEEL TECHNOLOGY PERSON YEAR ALLOCATION BY PROJECT AREA



CONTINUOUS CASTING TECHNOLOGY

* Near Net Shape Casting of Strip
* Hot Ductility of Simulated Concast Slab
* Clean Steel Production

FLAT ROLLED PRODUCTS

* Theromechanical Processing of Microalloyed Plate Steels
* Microstructure and Properties of Drawing Quality Steels
* Process Modelling of Strip Rolling

SHAPED PRODUCTS

* Microalloyed Seamless Tube
* Steels for Automotive Coil Springs
* Machinability of Medium Carbon Steels
* Rail Steels

DOUG BOYD (LEFT)
992-6674

ALF CRAWLEY (RIGHT)
992-2448

MANAGERS
STEEL TECHNOLOGY PROGRAM

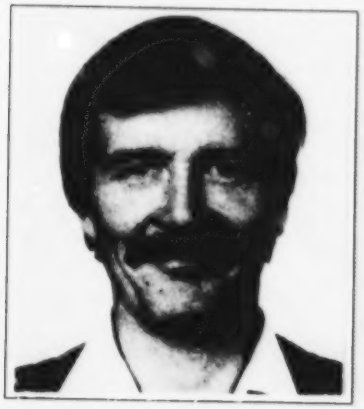
STEEL TECHNOLOGY

The objective of the MTL Steel Technology Program is to support the acquisition and development of new technology by the Canadian steel industry. Several important communication links with the industry are maintained to continually review MTL program priorities: MTL participates actively in the Canadian Steel Industry Research Association (CSIRA), with two people serving on the Board of Directors. CSIRA has a running Strategic Plan which identifies major technology development objectives of the steel industry. MTL participates in most CSIRA-sponsored activities such as international industrial visits, and national and international symposia and workshops. There is regular communication between MTL and individual steel companies concerning specific projects. During 1987/88 a Technical Advisory Group (TAG) comprising representatives of steel companies and steel users was formed to provide further guidance to the MTL Steel Technology Program.

CONTINUOUS CASTING TECHNOLOGY

NEAR NET SHAPE CASTING OF STRIP

Laboratory equipment and processing techniques were developed to produce directly cast steel strip for metallurgical studies of this novel material. A horizontal parallel plate caster was constructed to produce simulated strip cast material 6-mm thick. Aluminum-killed drawing quality (AKDQ) steel was produced by this method, and subsequently processed by hot rolling, cold rolling and annealing. Preliminary results indicate satisfactory formability. A single wheel strip caster was also constructed and an operational technique developed using low-melting-temperature alloys. Type 304 stainless steel and AKDQ steel were cast by this process as strip 115 mm wide x 0.75-1 mm thick. The apparatus is being upgraded by the addition of a roller-driven strip discharge chute.

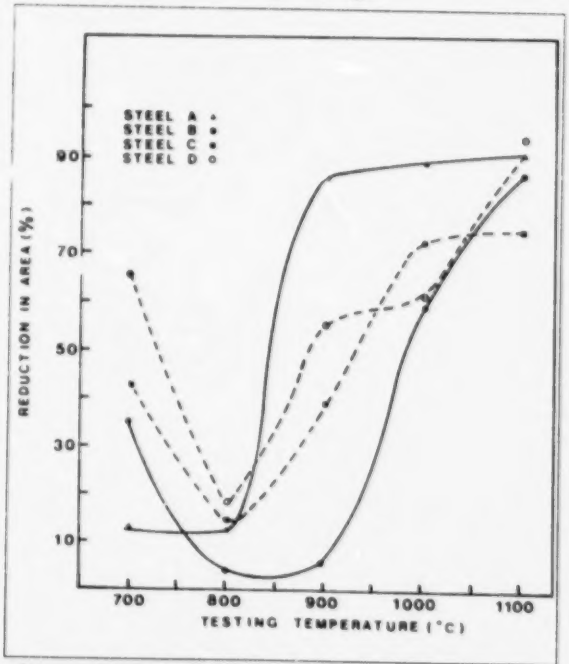


JOHN BOWKER

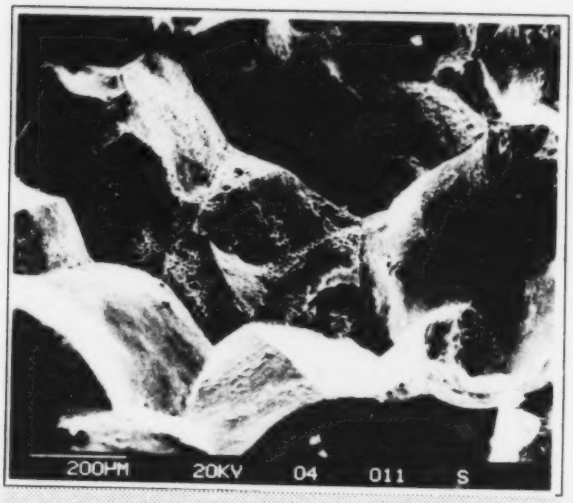
Project Leader
Continuous Casting Technology
992-7887

HOT DUCTILITY OF SIMULATED CONCAST SLAB

The Gleeble thermomechanical simulator was used to simulate hot transverse cracking of concast slab in material representative of the surface region. A total of 12 commercial steels were investigated. Tests on steels containing Mg or Te for sulphide shape control showed that Mg improves hot ductility while Te has a detrimental effect. The effects of Nb, Al, V and Ti on hot ductility are currently being investigated.



Comparison of the hot ductility curves for four C-Mn steels obtained under simulated continuous casting conditions of in-situ melting, solidification and hot tensile testing



SEM of fracture surface of simlated concast steel tested at 800°C

CLEAN STEEL PRODUCTION

Work continued on processes for producing 20-150 kg laboratory melts representative of modern concast steels. Vacuum melting and Ca-injection processes were developed for controlling levels of sulphur, oxygen and nitrogen. The current minimum levels of impurity elements in steels produced by MTL, and target levels for future process development are as follows:

	S ppm	P ppm	O ppm	N ppm	H ppm
Current minimum	10	50	40	20	1
Future target	5	20	10	10	1

Approximately 500 heats of experimental steels were made for MTL projects and for external clients.

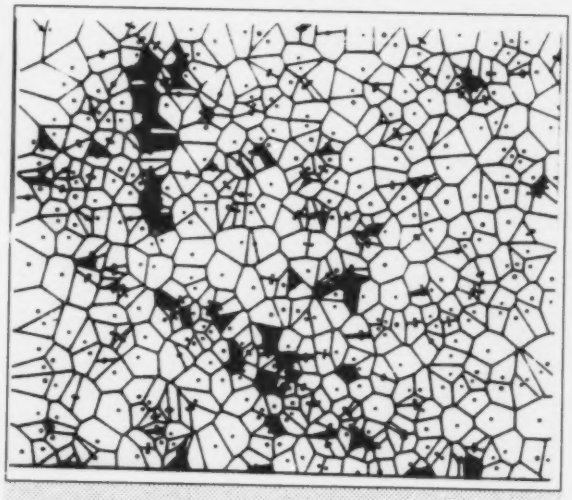
FLAT ROLLED PRODUCTS

THERMOMECHANICAL PROCESSING OF MICROALLOYED PLATE STEELS

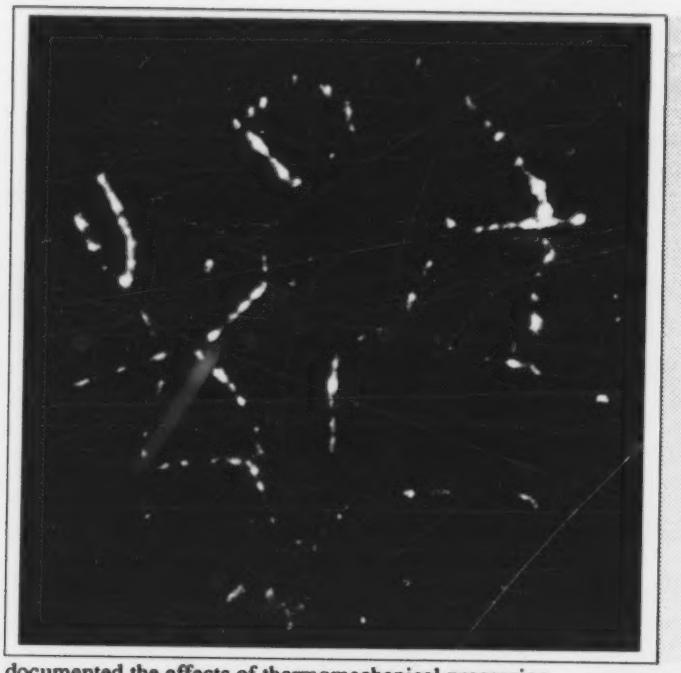
An extensive program was carried out to explore novel steel compositions and thermomechanical processing for the production of high-strength plate having good toughness and weldability. It was demonstrated that Nb and Ni-V microalloying combined with controlled rolling and on-line accelerated cooling (OLAC) produces plate in the 500-600 MPa strength range having exceptional toughness. Ultra low carbon bainitic (ULCB) steels in the 400-500 MPa strength range were investigated to determine the specific effects of B (15-30 ppm), N (30-100 ppm), C (0.02-0.06), and cooling rate (1-10°C/s). The effectiveness of boron in controlling the microstructure is strongly dependent on thermomechanical processing and inclusion distribution. Boron segregation was characterized for each alloy condition by secondary ion mass spectroscopy (SIMS). High strength, high toughness steels in the 550-650 MPa strength range were investigated for their suitability for naval vessel construction. New low-carbon, microalloyed grades (HSLA80) were compared with conventional low-alloy grades (HY80). The microalloyed grades exhibited a good combination of properties, notably greatly improved weldability which obviates the need for preheat and post heat in ship construction. Basic research projects on microalloyed steels

ALF CRAWLEY

Project Leader
Flat Rolled Products
992-2948



Computer plot of inclusion distribution in a plate steel showing regions of high local concentrations of particles ("clustering").



SIMS direct-ion image illustrating non-equilibrium boron-segregation in an ultra-low carbon steel annealed at 900°C after cooling from 1200 C. The boron content of the steel is 30 ppm.

documented the effects of thermomechanical processing conditions on microstructural evaluation in Nb-V, Cr-V, and Ti-V steels. The role of microstructural constituents on brittle and ductile fracture initiation in a Ti-V steel was investigated, as was the precipitation of Nb-V(C,N) in simulated weld heat affected zones.

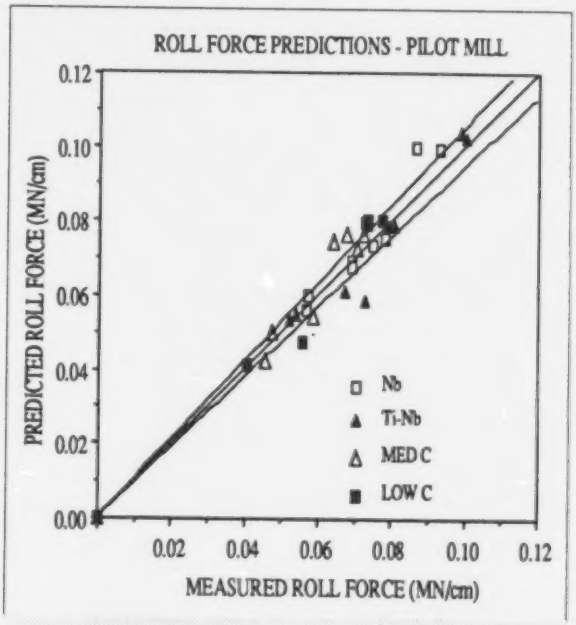
MICROSTRUCTURE AND PROPERTIES OF DRAWING QUALITY STEELS

Work continued on the direct measurement of through-thickness anisotropy (r-values) in commercial grade drawing quality steels. It was shown that the r-value is strain dependent and does not have a unique value for a given steel. A similar observation had been made in earlier work on dual phase steel, where the strain dependence was correlated with the structure and distribution of the two major phases. These results emphasize the inadequacy of using r-values as the only predictor of a steel's performance in a deep drawing operation.

This project is now focussed on the processing and characterization of interstitial-free (IF) steels. An MTL scientist has been seconded to a steel company to carry out research on batch-annealed, cold rolled IF sheet.

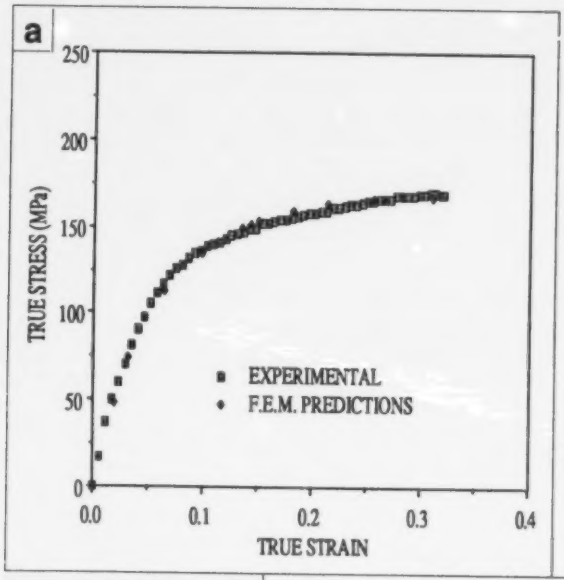
PROCESS MODELLING OF STRIP ROLLING

A commercial hot strip rolling schedule was simulated by cam plastometer experiments, and the data were used in the development of a one-dimensional model to predict roll forces and grain size. Rolling tests were also carried out on commercial transfer bar to determine actual rolling forces. Work started on a multi-client project to determine the flow stress behaviour of eight commercial steels by cam plastometer simulation of strip rolling.



Comparison of roll forces measured on the MTL pilot-scale rolling mill with model predictions

Work continued on the development of a coupled thermomechanical model for hot working processes. Excellent agreement was obtained between values of flow stress, strain distribution and temperature measured in cam plastometer tests, and values predicted by the model. The model is currently being applied to commercial roughing and strip mills, and to determine the thermomechanical history of rolls.



SHAPED PRODUCTS

MICROALLOYED SEAMLESS TUBE

Work began on rolling mill trials of a Ti-V-N steel for seamless tubes. The objective is to simulate the thermomechanical processing of a seamless tube mill to produce a lower cost product having high strength, improved weldability and resistance to hydrogen-induced cracking.

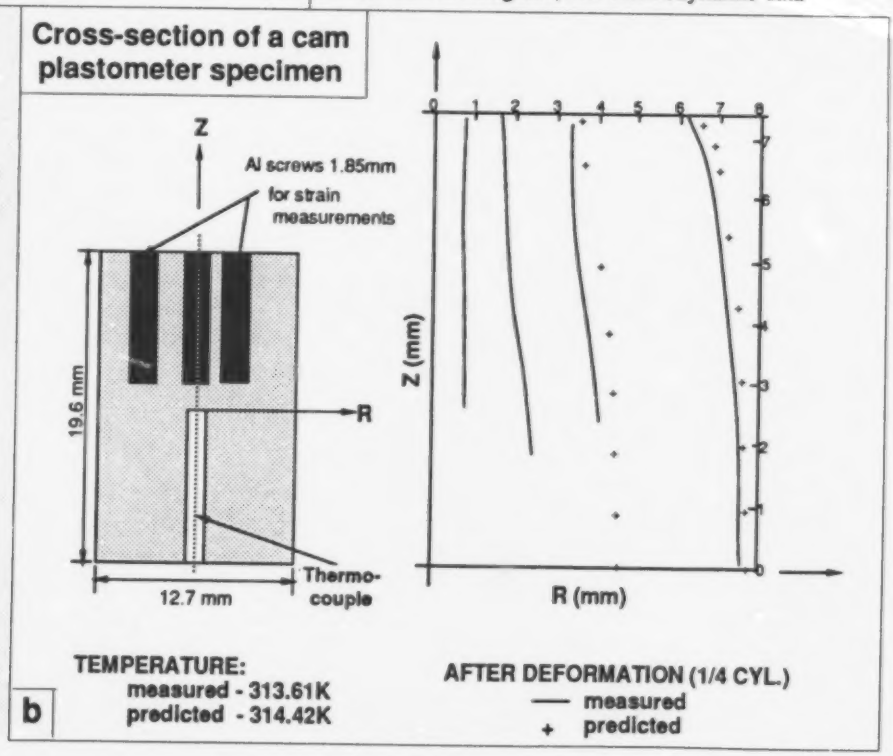
STEELS FOR AUTOMOTIVE COIL SPRINGS

Laboratory heats of 10 experimental steels were prepared and processed to 13 mm diameter rod at R_c 50. Tensile and fatigue properties were determined, and the Bauschinger Effect was measured to evaluate sag resistance. The best combination of properties was exhibited by high-Si steels microalloyed with Nb and V.

MACHINABILITY OF MEDIUM CARBON STEELS

Work was supported at McMaster on the effects of inclusions and microstructure on damage mechanisms associated with chip formation over a range of cutting speeds. A continuum model of the machining process was developed. The effects of inclusions on tool wear were also investigated, and thermodynamic data

Comparison of finite element predictions with cam plastometer tests for a) flow stress and b) temperature and strain distribution



GEORGE RUDDLE

Project Leader
Shaped Products
992-2948

pertaining to controlling inclusions in Ca-treated steels were determined ("inclusion engineering").

RAIL STEELS

A comprehensive monograph on rail steels is being prepared to summarize recent MTL research in this field, and to review the current state of this technology.

Major MTL Research Facilities and Capabilities

Metal Processing

400-50 kV X-ray units and 50c 1 v 192 γ-ray radiography.

Accelerated water-spray cooling system in line with rolling mill, flow rate controlled 0-1000 L/min, maximum cooling rate 30°C/s with 25 mm steel plate.

Acoustic emission testing system.

Aetna-Standard draw bench, 0.2 MN-23 kW capacity, 650 mm length, 25-6 mm diam dies.

Air induction furnaces, 450-25 kg capacities (steel rating).

Atmosphere-controlled heat treatment furnaces up to 1500 C.

Automation Industries C-scan system with immersion tank.

Canox C-SA-1000 square wave AC subarc narrow-gap welding machine.

Complete sand testing and mixing facilities.

Computer controlled cam plastometer for hot compression testing at strain rates of 5-300/s and temperatures up to 1250 C, up to four-hit sequencing, quenching.

Computerized tensile testing facility for determination of strain anisotropy in sheet metal.

Dominion-United pilot-scale rolling mill, single stand, reversing, 4.5 MN-225 kW capacity, 0-125 mm roll gap x 450 mm wide:

- two-high configuration, 450 mm diam work rolls with computerized data acquisition,
- four-high configuration, 150 mm diam work rolls.

Electroslag furnace, 50 kg capacity (steel rating).

ESAB subarc welding machine with 100 A AC and 1600A DC units with twin wire feed.

Fenn 6F hot swager, 50-23 mm diam die sets; Fenn 4F standard swager, 25-3 mm diam hot and cold die sets.

Finite element code for prediction of thermomechanical behaviour of metals during forming.

Gleeble 1500 thermomechanical simulator.

Hydraulic presses, 500 ton and 100 ton, for small-scale compaction, extrusion and forging.

Jarrel-Ash 7000 spectrograph and Fe, Cu, Al, Zn alloy standards.

Low-pressure die casting machine for Al, 225 kg capacity.

Magnetic particle and dye penetrant test facilities and standards.

Marco Materials enclosed melt spinner.

MMC quench-deformation dilatometer.

Two EM-3300 ET eddy current testing units.

Vacuum induction furnaces, 225-20 kg capacities (steel rating).

Property Determination

Cahn 1000 microbalance for high-temperature corrosion in controlled environment, maximum temperature 1000°C.

Cortest proving rings for NACE sulphide stress cracking test

EPD crack monitoring instrumentation with controlled temperature artificial sea-water, and A.C. pressure testing system for large pipes, maximum diam/length = 0.5/4 m, maximum pressure 55 MPa, with test capability to -40°C.

High temperature computer-controlled erosion-corrosion testing equipment, maximum temperature 1000 C.

K.O. Lee slicing and grinding machine for ceramics.

Large instrumented pendulum impact tester, 13 kJ.

LDJ 3500H hysteresigraph.

Mettler TA12 computerized thermogravimetric and differential thermal analysis equipment, maximum temperature 1100 C.

MTS universal servohydraulic computer controlled testing systems, maximum loads 100 and 500 kN with large environmental chamber for tests in -200 to +200 C range.

Residual stress measurement systems, using hole drilling and cut and section methods.

Slow strain rate equipment for sulphide stress cracking and stress corrosion cracking tests.

Three servohydraulic, computer controlled fatigue testing systems, maximum loads 250 and 500 kN. Equipped for corrosion fatigue testing in aqueous environments at -10 to +25 C.

Two 1000-L tank test facilities for marine corrosion studies.

Microscopic Examination and Analysis

Cambridge 100 scanning electron microscope linked to Quantimet 920 image analyzer and Link Energy Dispersive X-ray (EDX) analysis system.

Cambridge 250 Mk2 scanning electron microscope with Ortec 500 X-ray energy dispersive analysis system.

CAMECA electron probe microanalyzer with three wavelength spectrometers, one dedicated to soft X-ray, and an X-ray energy dispersive spectrometer.

CAMECA IMS-4f secondary ion mass spectrometer for trace isotope/element analysis (with high lateral and depth resolution) in metal mineral and semiconductor specimens.

CANMET/PROTO portable X-ray diffractometer for measurements of surface stresses in structures in the field.

Complete metallographic facility for ferrous, nonferrous, and some nonmetallic materials.

GE X-ray diffractometer for inverse pole figure determination.

Leco TC 136 analyzer for nitrogen and oxygen in steels.

Leybold-Heraeus 2002 analyzer of hydrogen in steels.

Philips EM 400T transmission/scanning transmission electron microscope with X-ray energy dispersive spectrometer and an electron energy loss spectrometer, 120 kV.

The Cameca IMS-4f Secondary Ion Mass Spectrometer

The CAMECA 4f secondary ion mass spectrometer (SIMS) is a highly specialized surface analysis instrument. Only the second of its kind in Canada, the $ 1.2 million ion microscope provides visual and analytical profiles of elements in various solids..

The SIMS is also referred to as an ion microscope because it can produce a highly magnified "map" of the surface it analyzes. In this mode, the instrument can be "tuned" to detect the distribution of different atoms in the surface of a specimen.

The SIMS works by atomic sputtering. As a beam of primary ions, usually cesium or oxygen, strikes the sample under investigation, secondary ions characteristic of elements in the sample sputter off the surface. These secondary ions are collected and analyzed according to their mass. The resulting data provide information about the elements present and a depth profile of their location. The instrument can detect trace elements at parts per billion, it has a lateral resolution of 0.2 µm and a depth resolution up to 50 Å. It also allows the analysis of light atoms such as boron, carbon, nitrogen , oxygen and hydrogen; elements difficult to identify by other analytical techniques.

Dr. Jennifer Jackman analysing a sample for Bell-Northern Research for the development of advanced semiconductor devices

The SIMS apparatus can be used to locate impurities which decrease the strength of welds, to analyze steels for elements that result in brittle properties at low temperature or to determine the distribution of atoms in semiconductor devices, to give but a few examples of its potential usage. Its sensitivity, resolution and ability to discriminate light ions make it a particularly useful tool. The instrument will be made available to researchers in other government departments and to the private sector via joint research projects with CANMET or on a cost recovery basis.

CAMECA SIMS Capabilities

- **Mass Spectrometer (Isotope Studies)**
  - Mass Resolution (m/Δm) 300 - 10 000
- **Range of Elements**
  - Masses 1-500 (Light Elements!)
- **Sensitivity** in the parts per million/parts/billion range
  - 10^{-5} to 10^{-9}
- **Depth Resolution (Depth Profile)**
  - 50 Å to 200 Å/Decade over 3-4 microns
- **Lateral Resolution (Elemental Maps)**
  - ~0.2 µm (Ion Microprobe)
  - < 1.0 µm (Ion Microscope)

MTL Cost Recovery

Research performed for industry played an increasingly important role in the activities of MTL during FY 87/88. Government policies now encourage all federal research laboratories to orient their programs toward helping their industrial clients and to make their facilities available to industry on a cost-recovery basis. These policies serve to reinforce the actions taken by MTL over the past several years to strengthen the ties between the Laboratories and the Canadian metals industry.

Cost recovery research completed during the year totaled $289,000, up from $97,000 in the previous fiscal year. Revenues from the Nondestructive Testing certification program were over $320,000.

Dr. J.B. Gilmour, Manager, Services to Industry (right) discusses the A.I.S.I. cost recovery project on the hot deformation of steel with Dr. D.L. Baragar (left), scientist responsible for the project.

A significant example of direct help to industry is the agreement reached with the American Iron and Steel Institute (AISI), acting on behalf of Stelco and seven other North American steel companies, for a $195,000 study of the hot deformation of steel. This research centres on the unique MTL cam plastometer and will be performed over a period of 18 months. The AISI also agreed to sponsor a Post Doctoral Fellow at MTL to work on mathematical modeling of the results of the cam plastometer research.

The acquisition of the SIMS enables MTL to offer a wider range of sophisticated surface analysis services to our clients. Revenues from research performed on the SIMS, EPMA and electron microscopes was nearly $100,000 and these revenues are expected to rise as more of our clients understand the usefulness of these techniques in solving industrial problems.

For further information about **Cost Recovery,** using MTL facilities and expertise, or joint **MTL/industrial projects** contact:

Dr. J.B. Gilmour
Manager, Services to Industry
Metals Technology Laboratories
568 Booth St., Ottawa, Ontario K1A 0G1
☎ (613) 995-8006

CANMET

PUBLICATIONS

CONFERENCE PROCEEDINGS EDITED BY MTL STAFF

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PMRL 87-51(J) Prediction of fatigue crack initiation lives for welded plate T-joints
G. Bhuyan and O. Vosikovsky

PMRL 87-56(J) Evaluation of weld zone corrosion of shipbuilding steel plates for use in the Arctic environment
R.J. Brigham, M. McLean, V. Donepudi, S. Santyr, L. Malik and A. Garner

PMRL 88-18(J) On the determination of Weibull parameters
B. Faucher and W.R. Tyson

INTERNAL REPORTS (INT)

PMRL 87-3(INT) Cameca ion probe procedures - Version 1
J.A. Jackman

PMRL 87-7(INT) Report of a trip to Arizona State University and Charles Evans Analytical Laboratory
J.A. Jackman

PMRL 87-20(INT) Evaluation of Olivine type sand sample for foundry use
E.J. Szabo and A.C. Kular

PMRL 87-25(INT) Vacuum melting of steel, Progress Report - March 1987
A.R. Palmer

PMRL 87-27(INT) Application of the CANMET stress diffractometer to aluminum alloys
R.A. Holt and P. Fryzuk

PMRL 87-28(INT) Introduction to the Ortec System 5000
V. Chartrand

PMRL 87-30(INT) Desulphurization of steels by powder injection, Progress Report - March 1987
A.R. Palmer

PMRL 87-31(INT) A basic guide to the 9250 SEM
V. Chartrand

PMRL 87-47(INT) Operating manual for the AVS vacuum furnace
A.R. Palmer and H.P. Guindon

PMRL 87-53(INT) Report on the 1987 Annual Assembly of IIW, Sofia, Bulgaria, July 5-11, 1987
J.E.M. Braid

PMRL 87-63(INT) Sample preparation of ceramic materials
K. Adams

PMRL 88-3(INT) The effect of phosphorus on the microstructure and properties of compacted graphite (CG) irons
G. Torga, S. Allende and K.G. Davis

CONFIDENTIAL REPORTS (CF)

Forty-three confidential or cost-recovery reports were completed by MTL in FY 87/88.

CONTRACT REPORTS

Welding engineering report #8, Narrow gap welding of Cr-Mo steels
Prepared by: *University of Alberta*
Scientific Authority: *J.T. McGrath*

Develop and evaluate the gas metal arc welding/submerged-arc welding process for improved weld properties. Final Report
Prepared by: *Stelco*
Scientific Authority: *J.T. McGrath*

A manual for the maintenance and modification of the hardware and software of the corrosion erosion tester control system
Prepared by: *J. Park*
Scientific Authority: *A.W. Lui*

Metallographic examination of corrosion test samples - Final Report Vol. 1 and 2
Prepared by: *AMCA*
Scientific Authority: *R. Brigham*

Final report on the evaluation of Al-Li-X ternary phase diagrams
Prepared by: *University of Manitoba*
Scientific Authority: *R.W. Revie*

Networking program for arctic and offshore energy development - Final report
Prepared by: *University of Alberta*
Scientific Authority: *R. Thomson*

Stress intensity factors for weld toe cracks in welded "T" plate joints - Final report
Prepared by: *Carleton University*
Scientific Authority: *O. Vosikovsky*

Study of the effect of titanium and sulphur on the toughness properties of weld metal deposits from low-hydrogen electrodes
Prepared by: *Canadian Liquid Air Ltd.*
Scientific Authority: *J.E.M. Braid*

Study of forgeability based on local strain and grain structure effects under various deformation rates and temperatures - Final report
Prepared by: *Metallurgical Engineering Department, Queen's University*
Scientific Authority: *J.J.M. Too*

Transmission electron microscope study of wear in disk of standard C-Mn composition - Final report
Prepared by: *University of Nova Scotia*
Scientific Authority: *D.M. Fegredo*

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